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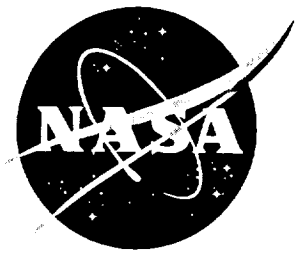

Eigensystem Realization Algorithm User's Guide for VAX/VMS Computers

Version 931216

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ABSTRACT

The Eigensystem Realization Algorithm (ERA) is a multiple-input, multiple-output, time domain technique for structural modal identification and minimum-order system realization. Modal identification is the process of calculating structural eigenvalues and eigenvectors (natural vibration frequencies, damping, mode shapes, and modal masses) from experimental data. System realization is the process of constructing state-space dynamic models [A,B,C,D] for modern control design. This User's Guide documents VAX/VMS-based FORTRAN software developed by the author since 1984 in conjunction with many applications. It consists of a main ERA program and 66 pre- and post-processors. The software provides complete modal identification capabilities and most system realization capabilities.

TABLE OF CONTENTS

ABSTRACT i
TABLE OF CONTENTS ii
LIST OF TABLES ix
LIST OF FIGURES x
LIST OF FILES xiii
GO Input Files xiii
VMS .COM Files xvi
User Input Files xvii

1.0 INTRODUCTION 1
1.1 Overview 1
1.2 Software Features 3
1.3 Hardware Requirements 4
1.4 Data Requirements 5
1.5 Software Initialization 5
1.5.1 Using ERA on a Local Host 5
1.5.2 Using ERA on a Remote Host 6
1.6 Acronyms 8
1.7 Trademarks 9
1.8 References 9

2.0 THEORY 12
2.1 MATLAB 2-DOF Example 14
2.2 Continuous vs Discrete State-Space Models 20
2.3 ERA With a Continuous State-Space Model 24
2.3.1 Formulation of ERA With Continuous Model 25
2.3.2 ERA Results For MATLAB 2-DOF Problem With Continuous Model . . . 30
2.4 ERA With a Discrete State-Space Model 37
2.4.1 Formulation of ERA With Discrete Model 38
2.4.2 ERA Results For MATLAB 2-DOF Problem With Discrete Model 41
2.5 Free Decay vs Impulse or Pulse Response Data 52
2.6 Accuracy Indicators 52
2.6.1 Consistent-Mode Indicator (CMI) 53
2.6.2 Extended Modal Amplitude Coherence (EMAC) 53
2.6.3 Modal Phase Collinearity (MPC) 56
2.6.3.1 Unweighted MPC 57
2.6.3.2 Phase Rotation For Free-Decay Data 57
2.6.4 Modal Strength Ratio (MSR) 57
2.6.5 Reciprocity 59
2.6.6 ZETA2 60

2.6.7 ARATIO 60
2.6.8 Reconstruction 61

3.0 DEMONSTRATION PROBLEM 64
3.1 Data Acquisition (ERAP2) 66
3.2 Data Preview (ERAG1) 72
3.3 Digital Filtering (ERAP20) 79
3.4 Selecting ERA Analysis Parameters 86
3.5 Running ERA 91
3.6 Examining the Tape50 Output File 94
3.7 Comparison of Identified Frequencies With Spectral Peaks (ERAG7) 107
3.8 MAC and/or Orthogonality Calculations (ERAP25 & ERAG25) 113
3.9 Mode Shape Plotting (ERAG5 or ERAG50) 120
3.9.1 Printer Plots on Tape51 (or Tape50) 121
3.9.2 DIGLIB Magnitude and Phase Plots (ERAG5) 124
3.9.3 Wireframe Mode Shape Plots (ERAG50) 128
3.9.4 Undeformed Wireframe Plots (ERAG50) 135
3.10 Looping Option 1 (No. of Retained Singular Values) 137
3.11 Looping Option 2 (Sliding Time Window) 151
3.12 Examining Distribution of CMI Values (ERAG3B) 157
3.13 Improvement of Results Using High Numbers of Assumed Modes 160
3.14 Improvement of Results Using KEYDTA 168
3.15 Modal Mass Calculation (ERAP11) 174
3.16 Reconstruction 179
3.16.1 Continuous-Time Reconstruction (ERAP10) 180
3.16.2 Discrete-Time Reconstruction (ERAP10B) 188

4.0 INPUT FILES 197
4.1 Tape1 Files 197
4.2 Coordinate-Code Files 199
4.3 User Input File 202
4.3.1 Field 1 - Input and Output Directory Names 204
4.3.2 Field 2 - Input and Output File Names 204
4.3.3 Field 3 - Array Dimensions 205
4.3.4 Field 4 - All Other Analysis Parameters 206
4.3.5 Field 5 - A 5-Line Job Description 207

5.0 OUTPUT FILES 208
5.1 Tape50 - Summary File 209
5.2 Tape51 - Mode Shape Printer Plots 209
5.3 Tape55 - Detailed EMAC Results 209
5.4 Tape79 - Output in MATRIXx Format 209
5.5 Tape85 - One-Line-Per-Eigenvalue Summary 213

5.6 Tape88 - Mode Shapes in Universal File Format. 214

6.0 ANALYSIS PARAMETERS 216
DATABW 216
F1 217
FMIN 217
FR1FIR 217
FR2FIR 217
ICAS85 218
IOMAC 218
IORDTU 218
IORFIR 219
IPRABC 219
IPRDTA 219
IPREMC 219
IPREVS 220
IPRHRS 220
IPRPAR 220
IPRPDQ 220
IPRREV 220
IREFTU 221
IRUNAV 221
ISTRIP 221
ITAPE() 222
ITAPES() 222
ITYDTA 222
KEYDTA() 223
LOOPOP 225
MCH 226
MIC 226
MIDOPT 226
MODELC 227
MODELD 228
MRH 228
MSRTOT 228
MSSCAL 229
MST 229
MTIM 230
MXALL 230
MXDATA 230
MXFLAG 231
MXHANK 231
MXMOMC 231

MXMTM 231
MXORDR 231
MXPDQT 232
N1 232
N2 232
N2LAST 233
N3 233
N3LAST 233
NCASES 233
NCH 234
NGENTH 234
NIC 234
NOAD79 234
NOFATL() 235
NRH 235
NSFLAG() 235
NSFRST 236
NSKIP 236
NST 236
NSTBOT 236
NSTDTA 237
NTIM 237
NUMRNK 237
PAR() 238
POFVAR 238
RNKTL0 239
RNKTOL 240
SF 240
T55CMI 240
T88CMI 240
WINDOW 240

7.0 RUNNING ERA 242
7.1 As a Batch Job 242
7.2 As an Interactive Job 243
7.3 As a Spawned Job 244

8.0 PRE- AND POST-PROCESSORS 245
8.1 Index of Pre- and Post-Processors 245
8.2 Running Pre- and Post-Processors With GO 247
8.3 Hidden Options 253

9.0 SISO AND MIMO TEST CASES 255

9.1 SISO 255
9.1.1 Test Case SISO1: 3 Modes, Noise-Free Data 256
9.1.2 Test Case SISO2: 30 Modes, Noise-Free Data 265
9.2 MIMO 272
9.2.1 Test Case MIMO1: 3 Modes, 1% Noise, Impulse Responses . . . 273
9.2.2 Test Case MIMO2: 3 Modes, 1% Noise, Pulse Responses 283

10.0 OTHER INTERESTING EXAMPLES 307
10.1 Example Problem EX001 307
10.2 Example Problem EX002 313
10.3 Example Problem EX003 318
10.4 Example Problem EX004 324
10.5 Example Problem EX005 329
10.6 Example Problem EX006 334
10.7 Example Problem EX007 339
10.8 Example Problem EX008 345
10.9 Example Problem EX009 350
10.10 Example Problem EX010 355
10.11 Example Problem EX011 359
10.12 Example Problem EX012 365
10.13 Example Problem EX013 372
10.14 Example Problem EX014 375
10.15 Example Problem EX015 380
10.16 Example Problem EX016 385
10.17 Example Problem EX017 390

11.0 COMMON MISTAKES 393

12.0 MISCELLANEOUS TOPICS 395
12.1 Running Graphics Pre- and Post-Processors as Batch Jobs 395
12.2 Erasing Tektronix Graphics 395
12.3 Bypassing Fatal Errors in ERA 396
12.4 Hidden Options in Pre- and Post-Processors 396
12.5 Redirecting the Output of Pre- and Post-Processors to a Disk File 397
12.6 Modifying Default Axis Numbers on Plots 397
12.7 Identification of Real Eigenvalues 400
12.8 Modification of Dimensions in a Pre- or Post-Processor and Recompilation 401
12.9 Viewing the Execution of ERA.COM 401
12.10 Increasing the Software Limit of 20 Inputs 402
12.11 Saving PostScript Files 402
12.12 Demonstration of ERAG4 407
12.13 NASTRAN Natural Frequencies of Mini-Mast Demonstration Problem 413

APPENDIX A - SOFTWARE INSTALLATION 417

APPENDIX B - COMPUTER-SPECIFIC PARAMETERS 423

APPENDIX C - ERROR MESSAGES 425

APPENDIX D - PRETEST PLANNING
MODAL RESPONSE AMPLITUDES VS. NOISE FLOOR 429

APPENDIX E - BIBLIOGRAPHY 446

APPENDIX F - DIRECTORY OF ALL FILES 458

APPENDIX G - NON-VAX USAGE 492

APPENDIX H - SOFTWARE MODIFICATIONS LOG (MODLOG.LIS) 496

APPENDIX I - GUIDELINES FOR SELECTING NCH AND NRH 531
I.1 Selecting NCH and NRH for Modal Test Applications 531
I.2 Selecting NCH and NRH for Control Applications 532

APPENDIX J - SINGULAR VALUE TRUNCATION 533
J.1 RNKTOL - Rank Tolerance 533
J.2 MXFLAG - Switch for Truncation at Largest Value of D(N)/D(N+1) 534
J.3 POFVAR - Cumulative Percentage of Data Variance 534
J.4 MXORDR - Maximum Number of Retained Singular Values 534

APPENDIX K - HANKEL MATRIX STRUCTURE 536

APPENDIX L - LISTINGS OF MATLAB .M FILES 538
build_ac_modal.m 538
build_ad_modal.m 538
eraw.m 538
figs4to6_theory_a.m 544
figs4to6_theory_d.m 545
hz_from_hs_and_zoh.m 546
irfs_af_theory.m 550
irfs_df_theory.m 553
lsim_foh.m 555
lsim_zoh.m 557
mimo1.m 558
modal_par_theory.m 559
okid_prfs_af_theory.m 560

okid_prfs_df_theory.m 563
prfs_af_theory.m 566
prfs_df_theory.m 568

LIST OF TABLES

Table 2-1. Modal Parameters of 2-DOF System 16
Table 2-2. Initial Values of the IRFs, $h_{kl}(0)$, $k = 1,2; l = 1,2$ 30
Table 2-3. ERA Results For MATLAB 2-DOF Problem Using Continuous-Time Model (IRFs) 35
Table 2-4. $D_a(1,1) = h_{a,11}(0) \cdot \Delta t$ For Various Values of Δt 36
Table 2-5. ERA Results For MATLAB 2-DOF Problem Using Discrete-Time Model (PRFs) . . 49

Table 3-1. Relationship of Percent Noise, SNR, and CPV 102

Table 6-1. Relationship of Percent Noise, SNR, and CPV 239

Table 10-1. ERA Results for Example Problem EX003 321
Table 10-2. MAC Correlation of EX004 (True) and EX005 Mode Shapes 333
Table 10-3. MAC Correlation of EX004 (True) and EX006 Mode Shapes 338

LIST OF FIGURES

Fig. 1-1. Eigensystem Realization Algorithm 2
Fig. 1-2. Practical Application of ERA 2

Fig. 2-1. Data Acquisition for Continuous Model Representation 12
Fig. 2-2. Data Acquisition for Discrete Model Representation 12
Fig. 2-3. Two Degree-of-Freedom System 15
Fig. 2-4. FRFs of Continuous System 17
Fig. 2-5. FRFs of Discrete System (Nyquist Frequency = 1 Hz) 19
Fig. 2-6. Comparison of FRFs of Continuous System (Solid Line) and Discrete System (Dashed Line), Nyquist Frequency = 1 Hz 20
Fig. 2-7. Comparison of FRFs of Continuous System (Solid Line) and Discrete System (Dashed Line), Nyquist Frequency = 10 Hz 20
Fig. 2-8. Relationship Between H(z) and H(s) 21
Fig. 2-9. Graphical Construction of $H_{a,11}(z)$ From $H_{a,11}(s)$ (Nyquist Frequency = 1 Hz) 22
Fig. 2-10. Comparison of $H_{a,11}(z)$ and Function Derived From $H_{a,11}(s)$ Using Method of Fig. 2-9 at Other Nyquist Frequencies 23
Fig. 2-11. Comparison of D/F IRFs: Time Simulation vs IFFT of FRF 31
Fig. 2-12. Comparison of A/F IRFs: Time Simulation vs IFFT of FRF 31
Fig. 2-13. D/F IRFs and FRFs: 2 Inputs (Cols), 2 Outputs (Rows) 34
Fig. 2-14. A/F IRFs and FRFs: 2 Inputs (Cols), 2 Outputs (Rows) 34
Fig. 2-15. Singular Values From ERA Analysis of IRFs 35
Fig. 2-16. Comparison of D/F PRFs: Time Simulation vs IFFT of FRF 42
Fig. 2-17. Comparison of A/F PRFs: Time Simulation vs IFFT of FRF 42
Fig. 2-18. Comparison of D/F PRFs: Time Simulation vs OKID With Initial Conditions 44
Fig. 2-19. Comparison of D/F PRFs: Time Simulation vs OKID Without Initial Conditions . . . 45
Fig. 2-20. D/F PRFs and FRFs: 2 Inputs (Cols), 2 Outputs (Rows) 46
Fig. 2-21. A/F PRFs and FRFs: 2 Inputs (Cols), 2 Outputs (Rows) 46
Fig. 2-22. Singular Values From ERA Analysis of PRFs 49
Fig. 2-23. D/F PRF vs Predicted PRF Using ERA-Identified Model 50
Fig. 2-24. A/F PRF vs Predicted PRF Using ERA-Identified Model 51
Fig. 2-25. Comparison of Data (Top) With Continuous-Time Reconstruction (Bottom) 62
Fig. 2-26. Comparison of Continuous-Time Reconstructed Spectrum (Solid Line) With Individual Modal Components (Dashed Lines) 62
Fig. 2-27. Comparison of Data (Top) With Discrete-Time Reconstruction (Bottom) 63
Fig. 2-28. Comparison of Discrete-Time Reconstructed Spectrum (Solid Line) With Individual Modal Components (Dashed Lines) 63

Fig. 3-1. Generation of Simulated Data for ERA 66
Fig. 3-2. Driving-Point IRF and FRF for Shaker 2 [G1B_DEMO] 78
Fig. 3-3. Digitally Filtered Driving-Point IRF and FRF for Shaker 2 [G1B_20_50_DEMO] . . . 86

Fig. 3-4. Truncation Errors With Bandlimited FRF Data 88
Fig. 3-5. Singular Values of Job INIT_20_50 [G3_DEMO] 103
Fig. 3-6. Identified Natural Frequencies (Job INIT_20_50) Superimposed on APS and MIF Functions [G7_DEMO] 109
Fig. 3-7. Test vs Analysis MAC Plot [P25_TA_20_50_DEMO and G25_DEMO] 118
Fig. 3-8. Amplitude-Weighted MAC Plot [P25_TA_20_50_GLOBAL_DEMO and G25_DEMO] 120
Fig. 3-9. Magnitude and Phase Mode Shape Plot [G5_2T_DEMO] 125
Fig. 3-10. Wireframe Mode Shape Plot [G50_2T_DEMO] 129
Fig. 3-11. Undeformed Shape With Numbered Measurement Locations [G50_UNDEFORMED_DEMO] 136
Fig. 3-12. Identified Natural Frequencies vs Assumed No. of Modes, with Lengths of Vertical Dashes Proportional to CMI [G15F_20_50_DEMO] 144
Fig. 3-13. Identification Results For Strongly Excited Mode at 30.7 Hz [G15_8_30P7_DEMO] 148
Fig. 3-14. Identification Results For Moderately Excited Mode at 23.5 Hz [G15_8_23P5_DEMO] 149
Fig. 3-15. Identification Results For Weakly Excited Mode at 37.3 Hz [G15_8_37P3_DEMO] 150
Fig. 3-16. Sliding Window Frequency Results [G15F_LO2_20_50_DEMO] 154
Fig. 3-17. Sliding Window Results From 30 to 33 Hz [G15_8_LO2_30TO33_DEMO] 156
Fig. 3-18. Distribution of CMI Values For Job INIT_20_50_LOOPOP1 Using 40 Assumed Modes [G3B_CMI_DEMO] 158
Fig. 3-19. Identified Natural Frequencies Using High Nos. of Assumed Modes [G15F_20_50_TO100_DEMO] 163
Fig. 3-20. Results For Strongly Excited Mode at 30.7 Hz Using High Nos. of Assumed Mdes [G15_8_30P7_TO100_DEMO] 165
Fig. 3-21. Results For Moderately Excited Mode at 23.5 Hz Using High Nos. of Assumed Modes [G15_8_23P5_TO100_DEMO] 166
Fig. 3-22. Results For Weakly Excited Mode at 37.3 Hz Using High Nos. of Assumed Modes [G15_8_37P3_TO100_DEMO] 167
Fig. 3-23. Improvement of Results For Weakly Excited Mode at 37.3 Hz Using KEYDTA (Compare With Fig. 3-15) [G15_8_KD37P3_DEMO] 173
Fig. 3-24. Comparison of Data (Top) With Continuous Time Reconstruction (Bottom) Using ERAP10 [G1B_P10_DEMO] 187
Fig. 3-25. Comparison of Total Reconstructed Spectrum (Solid Line) With Individual Modal Components (Dashed Lines) [G1F_P10_DEMO] 188
Fig. 3-26. Comparison of Data (Top) With Discrete Time Reconstruction (Bottom) Using ERAP10B [G1B_P10B_DEMO] 196

Fig. 8-1. Example Plot Generated by ERAG1 253

Fig. 9-1. Data and Spectrum of Test Case SISO1 (3 Modes) [G1B_SISO1] 259

Fig. 9-2. Data and Spectrum of Test Case SISO2 (20 Modes) [G1B_SISO2] 266
Fig. 9-3. Comparison of Data and ERAP10B-Calculated PRF for MIMO2 [G1T_MIMO2] . . 297
Fig. 9-4. Comparison of Data and MATLAB-Calculated PRF for MIMO2 Using [ad,bd,cd,dd] 302
Fig. 9-5. Comparison of Data and MATLAB-Calculated PRF for MIMO2 Using [ad_modal,bd_modal,cd_modal,dd_modal] 306

Fig. 10-1. Mode Shape Results for Example Problem EX004 (= True Mode Shapes) [G5_EX4] 328
Fig. 10-2. Mode Shape Results for Example Problem EX005 (Compare With True Mode Shapes, Fig. 10-1) [G5_EX5] 333
Fig. 10-3. Mode Shape Results for Example Problem EX006 (Compare With True Mode Shapes, Fig. 10-1) [G5_EX6] 338
Fig. 10-4. Mode Shape Results for Example Problem EX007 (ISTRIP = 3) [G5_EX7] 344
Fig. 10-5. Decreasing EMAC With Increasing N2LAST and N3LAST [G15_4_LO9_EX13] . 375
Fig. 10-6. Comparison of ZETA and ZETA2 [G15_4_LO-1_EX17] 392

Fig. 12-1. Unsatisfactory Default X-Axis Numbers [G7_21_22_DEMO] 398
Fig. 12-2. User-Specified X-Axis Numbers [G7_21_22_MODNUMS_DEMO] 400
Fig. 12-3. Reciprocity Check Between Driving Points 1 and 3 [G1F_SH1_SH3_RECIP_DEMO] 407
Fig. 12-4. Average Power Spectrum and Mode Indicator Function 413

Fig. D-1. Individual Modal Response Amplitudes vs. Noise Floor for Demonstration Problem of Chapter 3, 20-50 Hz [G92_DEMO] 430

LIST OF FILES

GO Input Files

Chapter 2

P10_IRFS_DF_IFFT.COM 61
P88_1_IRFS_DF_IFFT.COM 61
P88_2_IRFS_DF_IFFT.COM 61
G1B_P10_IRFS_DF_IFFT.COM 61
G1F_P10_IRFS_DF_IFFT.COM 61
P10B_1_PRFS_DF_IFFT.COM 61
P10B_2_PRFS_DF_IFFT.COM 61
P88_1_PRFS_DF_IFFT.COM 61
P88_2_PRFS_DF_IFFT.COM 61
G1B_P10B_PRFS_DF_IFFT.COM 61
G1F_P10B_PRFS_DF_IFFT.COM 61

Chapter 3

P2_DEMO.COM 67
G1B_DEMO.COM 73
G1T_DEMO.COM 74
G1F_DEMO.COM 74
P20_SH1_0_10_DEMO.COM 80
P20_SH2_0_10_DEMO.COM 80
P20_SH3_0_10_DEMO.COM 80
P20_SH1_20_50_DEMO.COM 80
P20_SH2_20_50_DEMO.COM 80
P20_SH3_20_50_DEMO.COM 80
P20_SH1_50_80_DEMO.COM 80
P20_SH2_50_80_DEMO.COM 80
P20_SH3_50_80_DEMO.COM 80
G1B_20_50_DEMO.COM 85
P21_20_50_DEMO.COM 86
G1B_FIR_20_50_DEMO.COM 86
G3_DEMO.COM 102
G4_DEMO.COM 107
G7_DEMO.COM 108
G7_LINEARMAG_DEMO.COM 109
P25_TA_20_50_DEMO.COM 114
G25_DEMO.COM 117
P25_TA_20_50_GLOBAL_DEMO.COM 119
G5B_20_50_DEMO.COM 124

G5_2T_DEMO.COM 125
G5_ANAL_2T_DEMO.COM 128
G50_2T_DEMO.COM 128
G50UNV_2T_DEMO.COM 133
G50_UNDEFORMED_DEMO.COM 136
G15F_20_50_DEMO.COM 140
G15_8_30P7_DEMO.COM 145
G15_8_23P5_DEMO.COM 145
G15_8_37P3_DEMO.COM 145
G15F_LO2_20_50_DEMO.COM 152
G15_8_LO2_30TO33_DEMO.COM 154
G3B_CMI_DEMO.COM 158
G15F_20_50_TO100_DEMO.COM 162
G15_8_30P7_TO100_DEMO.COM 164
G15_8_23P5_TO100_DEMO.COM 164
G15_8_37P3_TO100_DEMO.COM 164
G15_8_KD37P3_DEMO.COM 172
P11_DEMO.COM 176
P10_DEMO.COM 180
P88_1_DEMO.COM 184
P88_2_DEMO.COM 184
G1B_P10_DEMO.COM 187
G1F_P10_DEMO.COM 188
P10B_DEMO.COM 190
P88_DISCRETE_DEMO.COM 194
G1B_P10B_DEMO.COM 195

Chapter 8
G1B_DEMO.COM 247

Chapter 9
G1B_SISO1.COM 259
G1B_SISO2.COM 266
P10B_MIMO2.COM 289
P88_MIMO2.COM 293
G1T_MIMO2.COM 296
P79_MIMO2.COM 297

Chapter 10
G5_EX4.COM 327
G5_EX5.COM 331
G5_EX6.COM 336
G5_EX7.COM 342

G15_4_LO9_EX13.COM 373
G15_4_LO-1_EX17.COM 390

Chapter 12
G7_21_22_DEMO.COM 398
G7_21_22_MODNUMS_DEMO.COM 398
P5_201Z_203Z_DEMO.COM 404
P5_203Z_201Z_DEMO.COM 404
G1F_SH1_SH3_RECIP_DEMO.COM 406
G4_DEMO.COM 409
P26_8_DEMO.COM 413

Appendix D
P9_20_50_DEMO.COM 430
P10B_1_DEMO.COM 436
P10B_2_DEMO.COM 436
P10B_3_DEMO.COM 436
P92_DEMO.COM 442
G92_DEMO.COM 443

VMS .COM Files

Chapter 1
SUERA.COM 6
LOGIN.COM 6
SYLOGIN.COM 6
ERA.COM 7

Chapter 3
P20_ALL_DEMO.COM 80
SUERA_USER.COM 95

Chapter 9
RUN_SISO1.COM 256
RUN_SISO2.COM 265
RUN_MIMO1.COM 273

Chapter 10
EX001.COM 308
EX002.COM 313
EX003.COM 319
EX004.COM 325
EX005.COM 329
EX006.COM 334
EX007.COM 340
EX008.COM 345
EX009.COM 350
EX010.COM 355
EX011.COM 360
EX012.COM 365
EX013.COM 373
EX014.COM 375
EX015.COM 380
EX016.COM 386
EX017.COM 390

Chapter 12
BATCH_GRAPHICS_DEMO.COM 395
BUILD_SH1_SH3_RECIP_DEMO.COM 403
BUILD_T1_ALLDATA_DEMO.COM 408

Appendix G
DEMO.COM 492

User Input Files

Chapter 2

RF_DF_LSIM.ERA 32
IRF_DF_IFFT.ERA 32
IRF_AF_LSIM.ERA 32
IRF_AF_IFFT.ERA 32
PRF_DF_DLSIM.ERA 43
PRF_DF_OKID.ERA 43
PRF_AF_DLSIM.ERA 43
PRF_AF_OKID.ERA 43

Chapter 3

INIT_20_50.ERA 89
INIT_0_10.ERA 93
INIT_50_80.ERA 93
INIT_20_50_LOOPOP1.ERA 138
INIT_20_50_LOOPOP2.ERA 151
INIT_20_50_LO1_TO100.ERA 161
INIT_20_50_ANM31.ERA 169
INIT_20_50_KD37P3_LO1.ERA 171
INIT_20_50_MODELD.ERA 189

Chapter 9

SISO1.ERA 260
SISO2.ERA 266
MIMO1.ERA 275
MIMO2.ERA 284

Chapter 10

EX1.ERA 308
EX2.ERA 314
EX3.ERA 319
EX4.ERA 326
EX5.ERA 330
EX6.ERA 335
EX7.ERA 341
EX8.ERA 346
EX9.ERA 351
EX10.ERA 356
EX11.ERA 360
EX12.ERA 366
EX13.ERA 373

EX14.ERA 376
EX15.ERA 381
EX16.ERA 386
EX17.ERA 391

1.0 INTRODUCTION

1.1 Overview

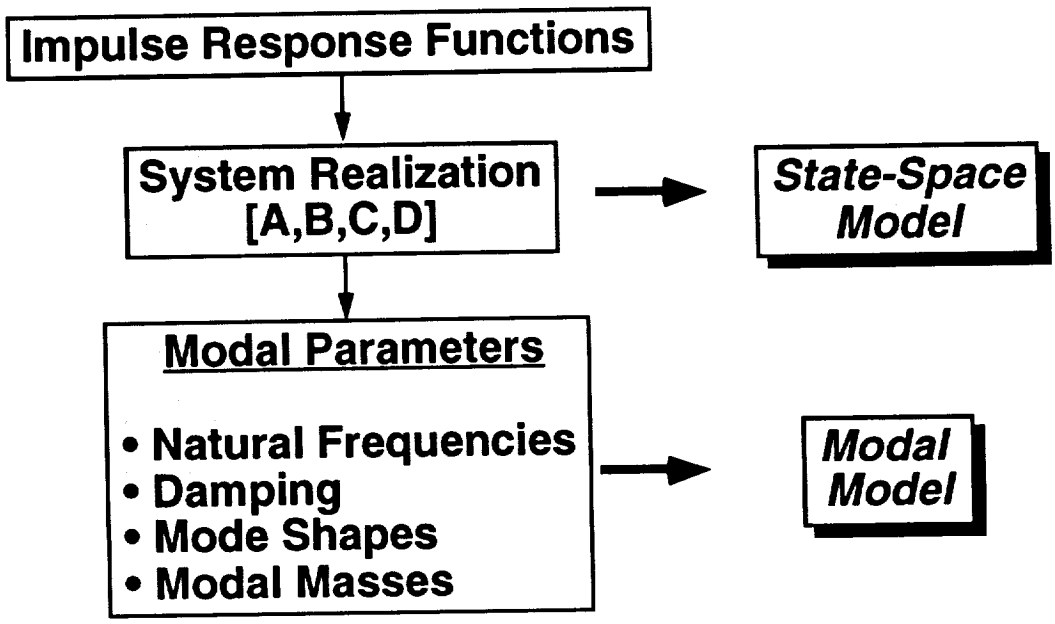
The Eigensystem Realization Algorithm (ERA) is a multiple-input, multiple-output, time domain technique for structural modal identification and minimum-order system realization. The name *Eigensystem Realization Algorithm* reflects the combination of modal testing technology involving the identification of structural eigenvalues and eigenvectors (natural frequencies, damping, mode shapes, and modal masses) and system realization theory involving the construction of state-space models [A,B,C,D] for modern control design. ERA was introduced in 1984 by the author and Dr. Jer-Nan Juang as a tool for system identification of future large space structures.

This User's Guide describes VAX/VMS-based FORTRAN software developed by the author **primarily for structural modal identification purposes.** Users interested in applying ERA primarily for control purposes should also consult Dr. Juang (804/864-4351) or Dr. Lucas Horta (804/864-4352) for information concerning other MATLAB-based subroutines.

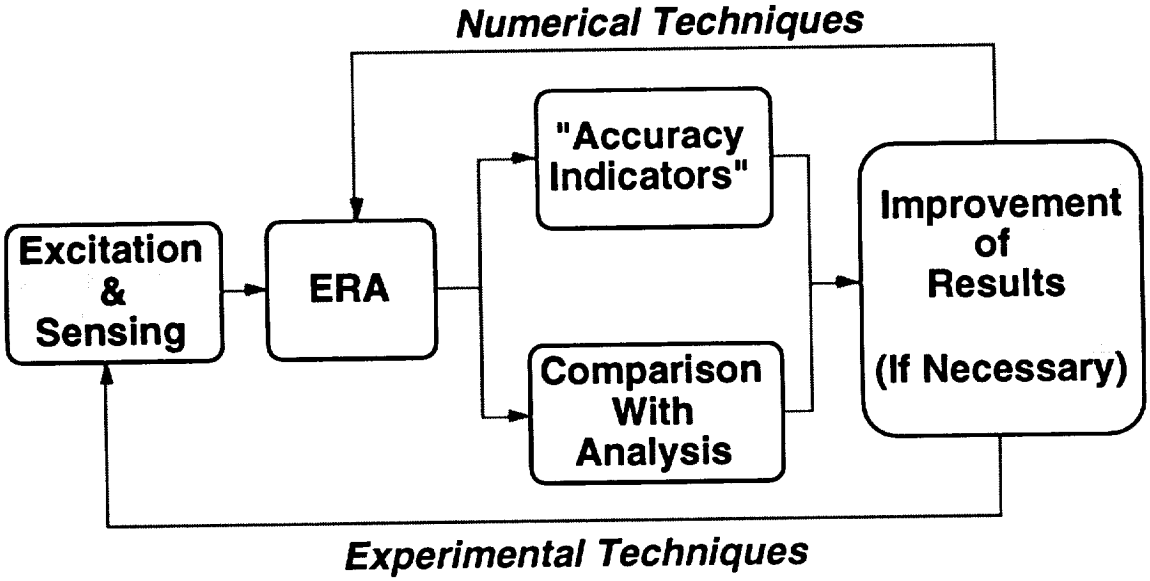
This software has evolved since 1984 in conjunction with many applications. The body of the main program (ERA) has changed very little since the beginning and is extremely reliable. There are no known bugs. There are also no known bugs in any of the 66 pre- and post-processor programs. If problems are encountered, however, please report them promptly to the author (804/864-4321). Suggestions for improvement are also appreciated.

New users should finish reading this introduction (Chapter 1), review the theory as necessary (Chapter 2), then work through the demonstration problem (Chapter 3). The demonstration problem covers 16 steps comprising a structural modal-identification application using frequency response functions. Chapter 9 contains additional test cases (SISO and MIMO). Users can generate their own simulated data sets using the SISO and MIMO procedures. For control applications, test case MIMO2 illustrates how ERA is used to develop discrete-time state-space models. Sections 2.1 through 2.4 compare in detail continuous and discrete state-space models using a MATLAB 2-degree-of-freedom example. Section 1.8 and Appendix E provide a list of references and a bibliography, respectively.

EIGENSYSTEM REALIZATION ALGORITHM



PRACTICAL APPLICATION OF ERA FOR MODAL IDENTIFICATION



1.2 Software Features

Features of this software package include:

- Easy operation of main program (ERA) using a single "User Input File."
- Simple data format easily interfaced with all sources of data.
- Numerous pre- and post-processors for utility and interpretation purposes.
- All pre- and post-processors are executed using a simple "GO" procedure.
- Graphics generated with DIGLIB public-domain software for device-independent output to many common graphics devices such as Tektronix terminals and PostScript printers.
- Data interfaces to SDRC TDAS or Modal-Plus (Universal File format) for structural dynamics analyses and MATLAB or MATRIXx for control analyses.
- Key analysis parameters can be incremented automatically for parametric studies.
- Sliding time window option for nonlinearity studies.
- KEYDTA feature for improving identification results of specific modes and/or minimizing Hankel matrix size with large data sets.
- Correlation tools for comparing identified mode shapes with analytical predictions (MAC and cross-orthogonality).
- "Accuracy indicators" for assessing relative accuracy of the identified modal parameters.
- Automatic re-dimensioning of small main program at run time to minimize memory requirements.
- Majority of computations performed in single precision to minimize execution time (adequate for experimental data).
- No limits on problem size.
- Software accessible from a remote host over DECNET.
- Programs written in standard FORTRAN 77, permitting use on other computers with only minor modifications.

1.3 Hardware Requirements

This software will operate on any VAX/VMS computer with a FORTRAN compiler.[1] Approximately 40,000 blocks of disk space (20 Mbytes) are required to store [ERA] and all subdirectories.

The primary text output file ("Tape50") uses 132-character line width. Therefore, it is helpful to have a line printer available. Alternatively, this file can be sent to a PostScript printer using the **LW132** command (LW = Laser Writer) available to all ERA users. The **LW132** command sends the designated file to a printer having the logical name PS_OUTPUT_DEVICE.

All graphics output from the pre- and post-processors is generated using a public-domain package known as DIGLIB. DIGLIB is an acronym for "Device Independent Graphics Library." This software provides device-independent output to many common graphics devices. The author uses a Tektronix 4107 window on a Macintosh (with VersaTerm-PRO terminal emulator) to preview graphics, routing them to a PostScript laser printer for hard copy. This combination of devices is fully supported and provides high-quality results.

Users can select from the following list of graphics devices:

```
 1 = TEK. 4010
 2 = TEK. 4014
 3 = TEK. 4025
 4 = TEK. 4107
 5 = TEK. 4115B
 6 = HP 2647/2648
 7 = DEC VT240
 8 = HPGL TALL
 9 = HPGL WIDE
10 = POSTSCRIPT TALL
11 = POSTSCRIPT WIDE
```

Many other devices are available if you wish to add them to the list of choices. Instructions for doing so are provided in the DIGLIB User's Guide contained in file ERA$DIGLIB:DIGLIB.DOC.[2]

[1] A FORTRAN compiler is necessary because the small main program (ERAMAIN.FOR) is redimensioned and then recompiled at run time. This minimizes memory requirements.

[2] It is not necessary to read the DIGLIB User's Guide in order to use the ERA software.

1.4 Data Requirements

This software requires *time-domain free response data*[3] (or equivalent, including impulse response functions[4], pulse response functions[5], randomdec signatures[6], or correlation functions[7]). There are no provisions for using other types of data such as frequency-domain functions or input/output time histories. **You must convert such data to ERA format prior to running the software.**

Several pre-processors are available to perform the necessary conversions from common data sources, such as program ERAP2 which converts frequency response functions (FRFs) stored in SDRC Type 58 Universal File format. ERAP2 generates impulse response functions in ERA format by inverse Fourier transformation of the FRFs. Also available are pre-processors ERAP2B, ERAP75B, and ERAP76B which convert free-response time histories in SDRC Universal files, MATRIXx ASCII files, and MATLAB binary files, respectively, to ERA format.

Additional information on Input Files is available in Chapter 4 and on Pre- and Post-Processors in Chapter 8. The operation of program ERAP2 is demonstrated in Section 3.1.

1.5 Software Initialization

Software installation instructions are provided in Appendix A. Install the software at this time if you have not already done so.

1.5.1. Using ERA on a Local Host[8]

---

[3]ERA decomposes free-response time histories into a summation of exponentially damped sinusoids representing the modes of the system.

[4]Impulse response functions are necessary for complete identification of [A,B,C,D] and/or all modal parameters including modal masses. If free-response data due to unknown excitation forces are used, valid [A,C] matrices and frequency, damping, and mode shapes are obtained but the identified [B,D] matrices and modal masses are meaningless. In practice, impulse response functions are normally obtained by inverse Fourier transformation of frequency response functions.

[5]For control applications where a discrete-time state space model at a particular data sampling rate is desired. The pulse response function is the response of the system to a unit-amplitude excitation applied at a particular input location for one data sampling period. It is the inverse Fourier transform of the discrete (z-domain) frequency response function, H(z).

[6]See Ref. 13.

[7]See Ref. 14.

[8]A local host is a computer with direct access to the disk containing the ERA software (stand-alone or clustered).

The ERA software is initialized on a local host by executing a command procedure named SUERA.COM as follows:

```
@ERA_DISK:[ERA]SUERA
```

where ERA_DISK is the disk on which the [ERA] directory is located. SUERA is an acronym for "Set Up ERA."

Normally, the `@SUERA` command is placed in your LOGIN.COM file so that it is executed automatically every time you log in. On some systems, the system manager may include SUERA.COM in the system LOGIN file (SYLOGIN.COM) so that ERA is initialized automatically for all users. If you perform ERA analyses as batch jobs (usually the case), the **`@SUERA`** command **must** appear in either your LOGIN file or in the SYLOGIN file.

Successful initialization of the software is indicated by the following message appearing on your computer screen:

```
ERA VERSION 931216
    installed.
```

If the version number you see is the same as shown here, everything in this User's Guide will function as described.[9] If you are using a different version, however, there will be some differences. Documentation of these differences is available "on-line" in file ERA$:MODLOG.LIS. MODLOG is an acronym for "Modifications Log." This file is also contained in Appendix H. It lists all significant software changes made since November 1989.

At NASA Langley, ERA (Version 931216) is stored on the SDBRP computer and is initialized from clustered computers SDBRP or SDBHR using the command:

```
@SDBRP$DKA0:[ERA_931216]SUERA_931216
```

1.5.2. Using ERA on a Remote Host[10]

To conserve disk space, a single copy of the ERA software can be shared by users on unclustered computers if they are connected by DECNET. Append the word 'REMOTE' to the end of the SUERA command (leaving a space between words) to access ERA located on a remote host, as follows:

---

[9]The Version Number specifies the year, month, and day of the last software modification.

[10]A remote host is a computer without direct access to the disk containing the ERA software (stand-alone or clustered), but can read the ERA files over DECNET.

```
@HOST::ERA_DISK:[ERA]SUERA REMOTE
```

where **HOST** is the DECNET name of the remote computer and ERA_DISK is the disk on which the software is stored.

At NASA Langley, ERA (Version 931216) is currently stored on the SDBRP computer and is initialized remotely using the command:

```
@SDBRP::SDBRP$DKA0:[ERA_931216]SUERA_931216 REMOTE
```

If you receive the following error messages,

```
%DCL-E-OPENIN, error opening HOST::ERA_DISK:[ERA]SUERA.COM; as input
-RMS-E-ACC, ACP file access failed
-SYSTEM-F-INVLOGIN, login information invalid at remote node
```

you must obtain Proxy Access for your computer. See your system manager. The ERA software can operate remotely only if Proxy Access is granted.

Successful initialization of the software is indicated by the following message appearing on your computer screen:

```
Remote access to ERA on HOST::ERA_DISK: has been established.

                    ERA VERSION 931216
                        installed.
```

If the version number you see is the same as shown here, everything in this User's Guide will function as described.[11] If you are using a different version, however, there will be some differences. Documentation of these differences is available "on-line" in file ERA$:MODLOG.LIS. MODLOG is an acronym for "Modifications Log." This file is also contained in Appendix H. It lists all significant software changes made since November 1989.

When ERA is used remotely, a small file named ERA.COM is copied into your login directory. If ERA.COM is accidentally deleted during a session, **SUERA** must be re-executed. You will receive the following warning message, which can be ignored, when **@SUERA REMOTE** is executed and a previous copy of ERA.COM does not exist in your login directory:

```
%DELETE-W-SEARCHFAIL, error searching for ERA.COM;*
-RMS-E-FNF, file not found
```

[11]The Version Number specifies the year, month, and day of the last software modification.

Accessing ERA over DECNET is usually only slightly slower than if a local copy is used. Of course, network traffic slows response time accordingly. Software modules are copied to the local computer at execution time. All software executes on the local computer.

1.6 Acronyms

APS	Average Power Spectrum (Eq. 12-1)
ARATIO	Amplitude Ratio (Eq. 2-73)
ASCII	American Standard Code for Information Interchange
CADA	Computer-Aided Dynamic Analysis software from LMS
CMI	Consistent-Mode Indicator (Eq. 2-48)
CPU	Central Processing Unit
CPV	Cumulative Percentage of Variance (Eq. 3-3)
DEC	Digital Equipment Corporation
DECNET	Network system of DEC computers
DIGLIB	Device-Independent Graphics Library from LLNL
DLSIM	Linear Simulation function in MATLAB (Discrete model)
DOF	Degrees of Freedom
EMAC	Extended Modal Amplitude Coherence (Eq. 2-57)
ERA	Eigensystem Realization Algorithm
FFT	Fast Fourier Transform
FIR	Finite Impulse Response (filter)
FRF	Frequency Response Function (Eqs. 2-10 and 2-13)
IFFT	Inverse Fast Fourier Transform
IRF	Impulse Response Function (Eq. 2-2)
ISI	Integrated Systems, Inc.
LaRC	Langley Research Center
LLNL	Lawrence Livermore National Laboratory
LMS	Leuven Measurement Systems, Inc.
LSIM	Linear Simulation function in MATLAB (Continuous model)
MAC	Modal Assurance Criterion (Eq. 3-10)
MATLAB	"Matrix Laboratory" software from The MathWorks, Inc.
MATRIXx	Software similar to MATLAB from ISI
MCM	Modal Controllability Matrix (Eq. 2-50)
MIF	Mode Indicator Function (Eq. 12-2)
MIMO	Multiple-Input, Multiple-Output
MOM	Modal Observability Matrix (Eq. 2-49)
MPC-U	Unweighted Modal Phase Collinearity (Section 2.6.3.1)
MPC-W	Weighted Modal Phase Collinearity (Eq. 2-61)
MSF	Modal Scale Factor (Eq. 3-12)
MSR	Modal Strength Ratio (Eq. 2-68)
NASTRAN	NASA Structural Analysis Program (Finite Elements)
OKID	Observer/Kalman filter Identification (Figs. 2-18 and 2-19)

PRC	Phase Resonance Criterion (Eq. 12-2)
PRF	Pulse Response Function (Eq. 2-5)
RMS	Root Mean Square
SDRC	Structural Dynamics Research Corporation
SISO	Single-Input, Single-Output
SNR	Signal-to-Noise Ratio (Eq. 3-2)
TDAS	Test Data Analysis Software from SDRC
VAX	Virtual Address eXtension computer from DEC
VMS	Virtual Memory (operating) System for VAX computers
ZETA2	A second damping-factor estimate (Eq. 2-70)
ZOH	Zero-Order Hold

1.7 Trademarks

CADA is a trademark of LMS International.
DEC, DECNET, VAX, and VMS are trademarks of Digital Equipment Corp.
I-DEAS and TDAS are trademarks of SDRC.
Macintosh is a trademark of Apple Computer Corp.
MATLAB is a trademark of The MathWorks, Inc.
MATRIXx is a trademark of Integrated Systems, Inc.
Microsoft is a trademark of Microsoft Corporation.
Microsoft Word is a trademark of Microsoft Corporation.
PostScript is a trademark of Adobe Systems, Inc.
VersaTerm-PRO is a trademark of Abelbeck Software.

1.8 References[1,2]

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[12]This list of references applies to the entire User's Guide. Appendix E contains an ERA bibliography covering 1984-1994.

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14. Kim, H. M., VanHorn, D. A., and Doiron, H. H., "Free-Decay Time-Domain Modal Identification for Large Space Structures," AIAA Paper 92-2208, April 1992.

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2.0 THEORY

ERA generates state-space models (and corresponding modal parameters) using either a continuous-time, state-space representation or a discrete-time, state-space representation. The vibration of structures is a continuous-time process governed by differential equations and continuous state-space models. However, if excitation is applied using zero-order hold (zoh) devices,[13] finite-dimensional, continuous-time linear systems are represented exactly at the sample times by difference equations and discrete state-space models (Ref. 19). Structural engineers usually use a continuous model representation for modal identification purposes whereas control engineers usually use a discrete model representation for system identification (system realization) purposes.

Figs. 2-1 and 2-2 show the customary data-acquisition configurations of structural and control engineers, respectively. In Fig. 2-1, sampled impulse response functions (IRFs) for ERA analysis are obtained from input-output sequences $u_1(k)$ and $y_1(k)$. In Fig. 2-2, pulse response functions (PRFs) for ERA analysis are obtained from input-output sequences $u_2(k)$ and $y_2(k)$. The IRFs and PRFs are often obtained by inverse Fourier transformation of frequency response functions, $Y(f)/U(f)$.

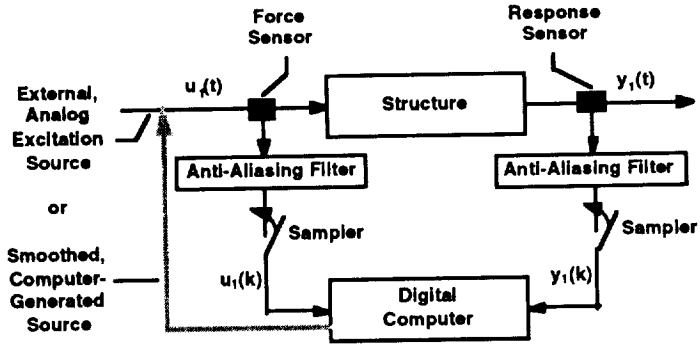


Fig. 2-1. Data Acquisition for Continuous Model Representation

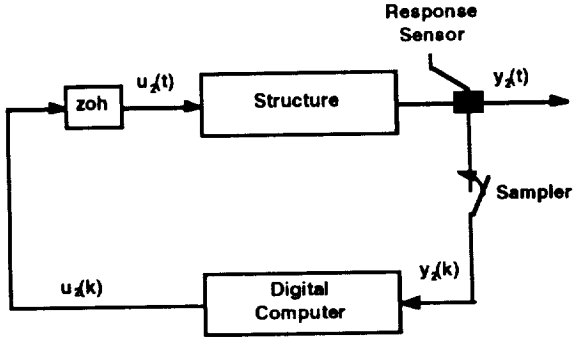


Fig. 2-2. Data Acquisition for Discrete Model Representation

[13]A zoh generates a constant output over a selected sampling interval.

Continuous-time, state-space models consist of matrices A_c, B_c, C, D satisfying the equations:

$$\begin{aligned} \dot{x}(t) &= A_c x(t) + B_c u(t) \\ y(t) &= Cx(t) + Du(t) \end{aligned} \tag{2-1}$$

where x is an n-dimensional state vector, y is a p-dimensional output vector, and u is a q-dimensional input vector. Note that $[A_c, B_c, C, D]$ is not unique since the set $[T^{-1}A_cT, T^{-1}B_c, CT, D]$, for any nonsingular matrix T, also satisfies Eq. 2-1.

The impulse response function (IRF)[14] equals:

$$Y_c(t) = Ce^{A_c t}B_c + D\delta(t) \qquad for\ t \geq 0. \tag{2-2}$$

Sampling the IRF at a uniform rate of f_s samples per second produces the sequence:[15]

$$Y_c(k) = CA^kB_c \qquad for\ k = 0,1,2,\cdots \tag{2-3}$$

where $A = e^{A_c \Delta t}$ is the state-transition matrix and $\Delta t = 1/f_s$ is the data sampling interval.

Discrete-time, state-space models consist of matrices A, B, C, D satisfying the equations:

$$\begin{aligned} x(k+1) &= Ax(k) + Bu(k) \\ y(k) &= Cx(k) + Du(k) \end{aligned} \tag{2-4}$$

where x is an n-dimensional state vector, y is a p-dimensional output vector, and u is a q-dimensional input vector. Note that $[A, B, C, D]$ is not unique since the set $[T^{-1}AT, T^{-1}B, CT, D]$, for any nonsingular matrix T, also satisfies Eq. 2-4.

---

[14]Each column of $Y_c(t)$, the IRF matrix, is the response of a continuous-time system to a unit impulse excitation ($u(t) = \delta(t)$, the Dirac delta function) applied at a specified input location to the system at rest ($x(0) = 0$).

[15]The $D\delta(t)$ term of Eq. (2-2) can be ignored for modal identification purposes. If necessary, the D matrix can be calculated from ERA-identified mass-scaled mode shapes, Φ (generated with ERA post-processor program ERAP11, described in Section 3.15) using Eq. 2-9. Or it can be approximated from sampled IRF data (obtained by inverse Fourier transformation of FRFs) using the technique illustrated in Section 2.3.2 (Table 2-4). The approximation improves as Δt decreases.

The pulse response function (PRF)[16] equals:

$$Y(k) = \begin{cases} D & for\ k = 0 \\ CA^{k-1}B & for\ k = 1,2,3,\cdots \end{cases} \tag{2-5}$$

ERA uses sampled impulse response functions $Y_c(k)$ (Eq. 2-3) to identify continuous state-space models $[A_c, B_c, C]$ or pulse response functions $Y(k)$ (Eq. 2-5) to identify discrete state-space models $[A, B, C, D]$. Modal parameters are obtained from the identified state-space models by solving a subsequent eigenvalue problem.

Note the similarity of Eqs. 2-3 and 2-5. The same ERA algorithm is used to identify either $[A_c, B_c, C]$ or $[A, B, C, D]$.[17] The only difference is that the analysis of IRFs begins at the first data point, $Y(0)$, whereas analysis of PRFs begins at the second data point, $Y(1)$, with the first data point, $Y(0)$, set equal to D.

The remainder of this chapter covers the following topics. Section 2.1 describes a MATLAB 2-degree-of-freedom example problem used to illustrate the concepts discussed in this chapter. Section 2.2 compares the $[A, B, C, D]$ system matrices and frequency response functions (FRFs) of a continuous-time model with the corresponding system matrices and FRFs of a discrete-time model. The details of continuous and discrete state-space model representations and associated ERA solutions are then given in Sections 2.3 and 2.4, respectively. Section 2.5 explains the differences between using arbitrary free-decay responses (without excitation information) and using impulse or pulse response functions in the ERA analysis. Section 2.6 documents various "accuracy indicators" for assessing the relative accuracy of ERA-identified modal parameters.

2.1 MATLAB 2-DOF Example[18]

A two-degree-of-freedom system with masses m_1 and m_2, viscous dashpots $g_1 = g_2 = g$, and stiffnesses $k_1 = k_2 = k$, see **Fig. 2-3**, is governed by the equation of motion:

$$M\ddot{y} + G\dot{y} + Ky = f \tag{2-6}$$

[16]Each column of $Y(k)$, the PRF matrix, is the response of a discrete-time system to a unit pulse excitation ($u(0) = 1$ and $u(k) = 0$ for $k \geq 1$) applied at a specified input location to the system at rest ($x(0) = 0$).

[17]With IRFs, A is obtained from the ERA analysis based on Eq. 2-3. A_c (diagonalized) can then be calculated from the eigenvalues of A and Δt. It is unnecessary, however, to calculate A_c to identify modal parameters.

[18]All MATLAB .m files discussed in this User's Guide are listing in Appendix L.

where $M = \begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix}$, $G = \begin{bmatrix} 2g & -g \\ -g & 2g \end{bmatrix}$, and $K = \begin{bmatrix} 2k & -k \\ -k & 2k \end{bmatrix}$. The applied force vector is $f = \begin{bmatrix} f_1 \\ f_2 \end{bmatrix}$. The resulting displacement of the masses is $y_d = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}$, and the corresponding acceleration of the masses is $y_a = \begin{bmatrix} \ddot{y}_1 \\ \ddot{y}_2 \end{bmatrix}$. Both displacement/force and acceleration/force situations will be discussed. The displacement/force case is representative of systems without a D matrix ($D = 0$), and the acceleration/force case is representative of systems with a D matrix.

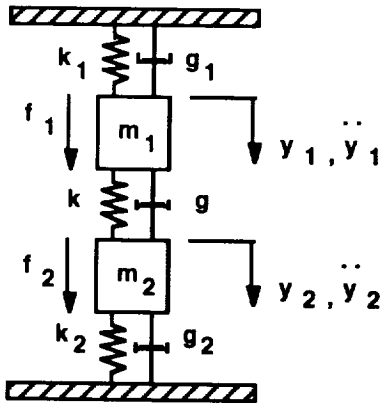


Fig. 2-3. Two Degree-of-Freedom System

Eq. 2-6 can be expressed in state-space form as:

$$\begin{aligned} \dot{x} &= A_c x + B_c f \\ y_d &= C_d x + D_d f \\ y_a &= C_a x + D_a f \end{aligned} \tag{2-7}$$

where

$$A_c = \begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}G \end{bmatrix},\ B_c = \begin{bmatrix} 0 \\ M^{-1} \end{bmatrix},\ C_d = [I \quad 0],\ D_d = 0,$$

$$C_a = \begin{bmatrix} -M^{-1}K & -M^{-1}G \end{bmatrix},\ D_a = M^{-1}, \text{ and } x = \begin{bmatrix} y \\ \dot{y} \end{bmatrix}, \text{ with } y = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}.$$

Note that this 2-DOF system with viscous damping requires a 4th-order state-space model (A_c is 4 x 4). The system contains 2 modes, corresponding to 2 pairs of complex-conjugate eigenvalues.

Transform the system to modal coordinates using the familiar transformation

$$y = \Phi q \tag{2-8}$$

as follows:

$$\begin{aligned} \dot{\underline{x}} &= \underline{A}_c \underline{x} + \underline{B}_c f \\ y_d &= \underline{C}_d \underline{x} + \underline{D}_d f \\ y_a &= \underline{C}_a \underline{x} + \underline{D}_a f \end{aligned} \tag{2-9}$$

where

$$\underline{A}_c = \begin{bmatrix} 0 & I \\ diag(-\omega_{ni}^2) & diag(-2\zeta_i\omega_{ni}) \end{bmatrix},\ \underline{B}_c = \begin{bmatrix} 0 \\ \Phi^T \end{bmatrix},\ \underline{C}_d = [\Phi \quad 0],\ \underline{D}_d = D_d = 0,$$

$$\underline{C}_a = \Phi\left[diag(-\omega_{ni}^2) \quad diag(-2\zeta_i\omega_{ni})\right],\ \underline{D}_a = D_a = \Phi\Phi^T,\ \underline{x} = \begin{bmatrix} q \\ \dot{q} \end{bmatrix}, \text{ and}$$

Φ = mode shape matrix = $[\phi_1 \quad \phi_2]$,
where ϕ_i = mass-scaled mode shape i (modal mass[19] = 1.0)
ω_{ni} = undamped natural frequency (rad/sec) of mode i
ζ_i = modal damping factor (fraction of critical damping) of mode i.

Now, numerical values are given to the various physical parameters. Let $m_1 = 0.8$, $m_2 = 1.5$, $g = 0.1$, and $k = 10$. The modal parameters of this system are shown in **Table 2-1**:[20]

Mode	Damped Natural Frequency, Hz	Damping Factor, %	Amplitude-Scaled Mode Shape (Max. Ampl. = 100.00)	Mass-Scaled Mode Shape (Modal Mass = 1.0)
1	0.4594	1.443	75.00 100.00	0.5371 0.7161
2	0.8714	2.739	100.00 -40.00	0.9806 -0.3922

Table 2-1. Modal Parameters of 2-DOF System

[19]Modal mass, $\underline{M}$, is defined as $\underline{M} = \Psi^T M \Psi$ for arbitrarily-scaled mode shapes ψ_i. Mode shapes scaled to unity modal mass, ϕ_i, satisfy the equation $\Phi^T M \Phi = I$.

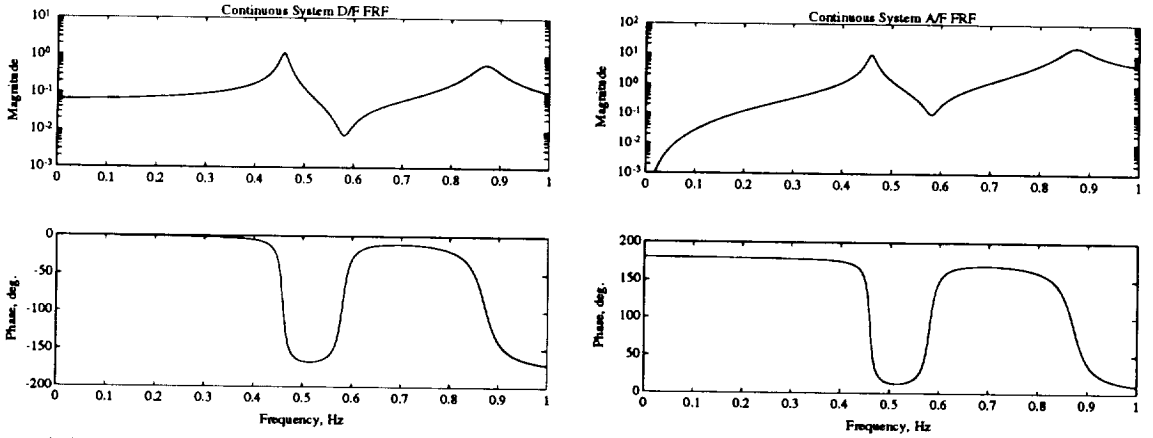
[20]Table 2-1 is generated with MATLAB file ERA$MATLAB:MODAL_PAR_THEORY.M. The damped natural frequency in Hz, f_{di}, equals $(\omega_{ni}/2\pi)\cdot\sqrt{1-\zeta_i^2}$. ERA identifies damped natural frequencies.

The matrices of displacement/force and acceleration/force frequency response functions (FRFs) of the system are (Ref. 17):

$$H_{d,kl}(s) = C_d(sI - A_c)^{-1}B_c + D_d$$
$$H_{a,kl}(s) = C_a(sI - A_c)^{-1}B_c + D_a \qquad (2\text{-}10)$$

where $s = j\omega$. Row k of each $H(s)$ matrix contains FRFs for output k. Column l contains FRFs for input l.

As an example, the s-domain FRFs from Force No. 1 to Response No. 1, $H_{d,11}(j\omega)$ and $H_{a,11}(j\omega)$, are shown in **Fig. 2-4.**[21]



(a) Displacement/Force, $H_{d,11}(j\omega)$ **(b) Acceleration/Force, $H_{a,11}(j\omega)$**

Fig. 2-4. FRFs of Continuous System

These are classical driving-point FRFs of a linear, two-degree-of-freedom dynamic system. Similar functions are routinely measured in structural modal tests. There are two clearly defined resonances at approximately 0.46 and 0.87 Hz, and the phase angle fluctuates entirely between 0 and -180 degrees (or 0 and +180 degrees). Note that $H_{kl}(j\omega)$ is defined at all frequencies $-\infty \le \omega \le +\infty$. Only the portion of $H_{11}(j\omega)$ in the range of frequencies $f = \frac{\omega}{2\pi}$ from 0.0 to 1.0 Hz is shown in Fig. 2-4.[22]

[21]Figs. 2-4(a) through 2-6(a) and Figs. 2-4(b) through 2-6(b) are generated with MATLAB files ERA$MATLAB:FIGS4TO6_THEORY_D.M and FIGS4TO6_THEORY_A.M, respectively.

[22]Mathematically, it is of course impossible to measure $H(j\omega)$ in the laboratory since it extends from $\omega = -\infty$ to $\omega = +\infty$ and is defined at all frequencies. Practically, however, $H(j\omega)$ can be accurately measured in any desired bandwidth at a discrete number of points. When discussed in conjunction with ERA analysis, $H(j\omega)$ always refers to such bandlimited, sampled FRFs.

Experimentally, s-domain FRFs of structures are measured using the data-acquisition configuration shown in Fig. 2-1. Continuous, analog excitation and response signals, $u_1(t)$ and $y_1(t)$, are low-pass filtered (anti-aliasing filters) and then uniformly sampled to generate sequences $u_1(k)$ and $y_1(k)$. The anti-aliasing filters have very sharp attenuation rates, e.g., 96 dB/octave or greater. The sharp attenuation permits sampling rates as low as approximately 2.6 times the highest frequency of interest to be used. The selected combination of sampling rate and filter characteristics **guarantees alias-free data** in the bandwidth of interest (typically from 0 to 75% of the Nyquist frequency) by sufficiently attenuating all aliased frequency components in this bandwidth.[23] The input $u_1(t)$ is sufficiently rich to excite all modes in the bandwidth of interest. Multiple-input, burst-random excitation is often used in structural modal testing to obtain consistent data for multiple inputs while avoiding FFT leakage errors (Ref. 9).[24]

Note

Experimentally, s-domain FRFs identical to those in Fig. 2-4 are obtained using classical, steady-state sinusoidal excitation at each frequency (stepped sine dwell). This approach is seldom used in practice today, however, because it is usually much slower than using modern, random-excitation/FFT methods as described above.

If this structure is now considered to be the plant in a digital control system implemented as shown in Fig. 2-2, a discrete state-space model of the following form can be developed:

$$\begin{aligned} x(k+1) &= Ax(k) + Bu(k) \\ y(k) &= Cx(k) + Du(k) \end{aligned} \tag{2-11}$$

where the continuous and discrete A and B matrices are related as follows (Ref. 19):

---

[23] An example of commercially available hardware with these characteristics is the ZONIC 7000 system used at NASA Langley.

[24] The terminology "consistent data" used in modal testing refers to multiple sets of data having identical eigenvalues and eigenvectors. That is, there are no changes of test-article dynamic characteristics (through mass loading, temperature variation, boundary condition changes, etc.) among various data sets. Inconsistent data can cause difficulties for multiple-input identification methods such as ERA that assume invariant dynamic characteristics among multiple data sets analyzed simultaneously.

$$A = \exp(A_c \Delta t)$$
$$B = \int_0^{\Delta t} \exp(A_c(\Delta t - \tau)) B_c d\tau = A_c^{-1}(A - I)B_c \tag{2-12}$$

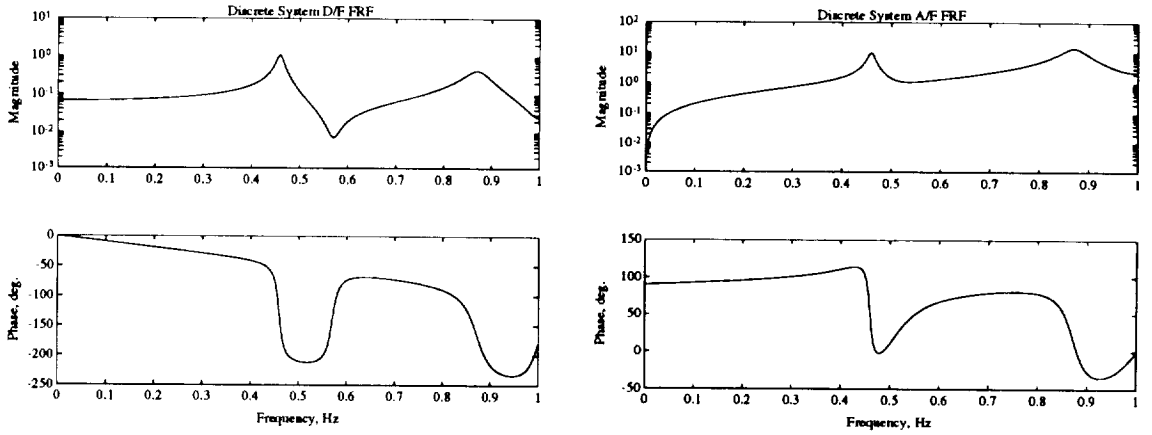
where Δt is the data sampling interval. The C and D matrices are identical in the continuous and discrete representations.

The matrices of displacement/force and acceleration/force frequency response functions (FRFs) of this system are (Ref. 17):

$$H_{d,kl}(z) = C_d(zI - A)^{-1}B + D_d$$
$$H_{a,kl}(z) = C_a(zI - A)^{-1}B + D_a \tag{2-13}$$

where z is evaluated at points on the unit circle from 0 to π ($z = e^{j\theta}$). An angle of 0 corresponds to 0.0 Hz. An angle of π corresponds to the Nyquist frequency of $1/2\Delta t$ Hz.[25] Row k of each $H(z)$ matrix contains FRFs for output k. Column l contains FRFs for input l.

As an example, the z-domain FRFs from Force No. 1 to Response No. 1, $H_{d,11}(e^{j\theta})$ and $H_{a,11}(e^{j\theta})$, with Δt = 0.5 sec, are shown in **Fig. 2-5**. These discrete-system FRFs, $H(z)$, are compared with the corresponding continuous-system FRFs, $H(s)$, in the next report section.



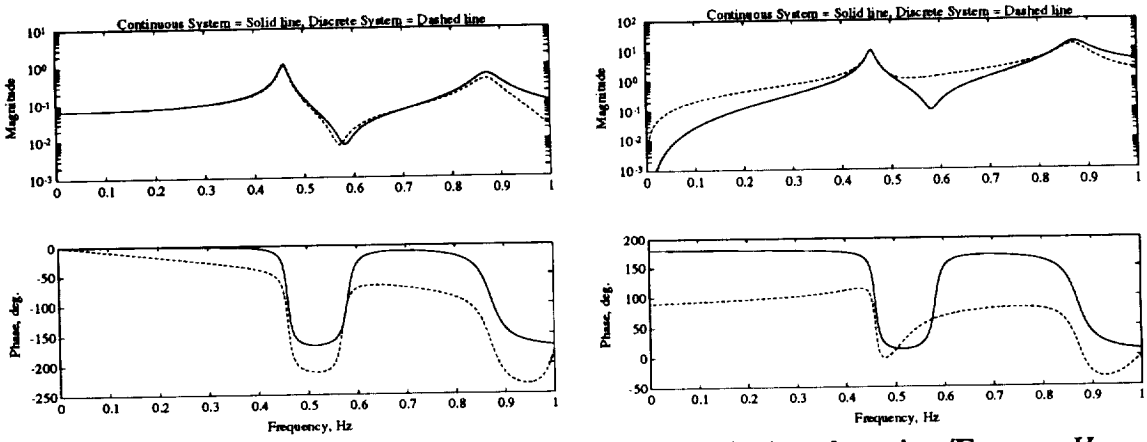
(a) Displacement/Force, $H_{d,11}(e^{j\theta})$ **(b) Acceleration/Force, $H_{a,11}(e^{j\theta})$**

Fig. 2-5. FRFs of Discrete System (Nyquist Frequency = 1 Hz)

[25] $H(z)$ on the lower half of the unit circle is the complex conjugate of $H(z)$ on the upper half of the unit circle.

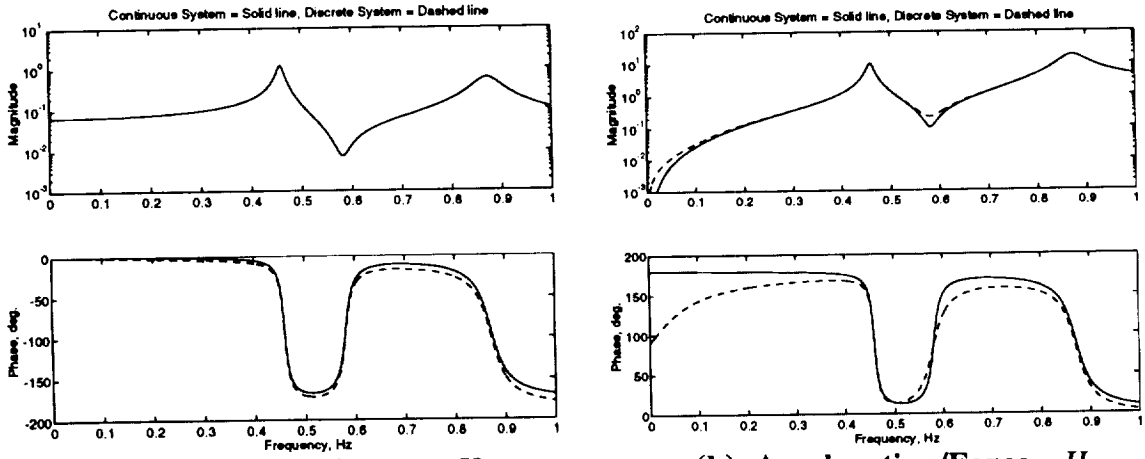
2.2 Continuous vs Discrete State-Space Models

Figs. 2-6 and 2-7 compare s-domain (continuous system) and z-domain (discrete system) FRFs with Nyquist frequencies of 1 and 10 Hz, respectively. The Nyquist frequency, or "folding frequency," is one-half the data sampling frequency. Significant differences occur with a Nyquist frequency of 1 Hz. With a Nyquist frequency of 10 Hz, however, the differences are much smaller. In practice, the data-acquisition configuration of Fig. 2-1 is sometimes used to measure FRFs for control design by choosing a Nyquist frequency at least 10 times greater than the highest frequency of interest. The differences between continuous and discrete models then become negligible.



(a) Displacement/Force, $H_{d,11}$ **(b) Acceleration/Force, $H_{a,11}$**

Fig. 2-6. Comparison of FRFs of Continuous System (Solid Line) and Discrete System (Dashed Line), Nyquist Frequency = 1 Hz



(a) Displacement/Force, $H_{d,11}$ **(b) Acceleration/Force, $H_{a,11}$**

Fig. 2-7. Comparison of FRFs of Continuous System (Solid Line) and Discrete System (Dashed Line), Nyquist Frequency = 10 Hz

It is instructive to examine the relationship between the FRF of a continuous system, $H(s)$, and the FRF of the corresponding discrete system, $H(z)$. $H(z)$ is related to $H(s)$ by the process shown in **Fig. 2-8**. "ZOH" represents the transfer function of the zero-order hold. $H(s)$ is premultiplied by ZOH and then the resulting transfer function is aliased (folded back and forth with complex-conjugation) at the Nyquist frequency. The individual steps are shown graphically in **Fig. 2-9**.[26] Here, the acceleration/force $H(z)$ of Fig. 2-6(b) is compared with that calculated by premultiplying $H(s)$ by ZOH, and then aliasing the result at the Nyquist frequency of 1 Hz. Exact equivalence with $H(z)$ is obtained, as shown in Fig. 2-9(h).[27] Note that the D matrix must be removed from the model prior to aliasing, and restored afterwards.

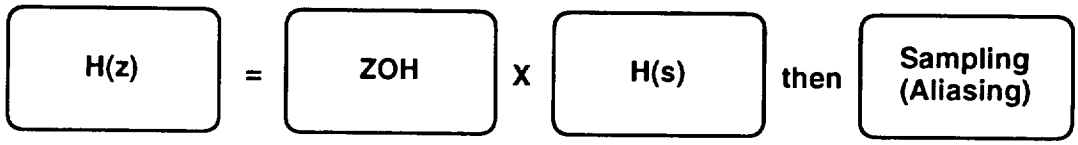


Fig. 2-8. Relationship Between H(z) and H(s)

The procedure illustrated in Fig. 2-9 is valid at all Nyquist frequencies. **Fig. 2-10** shows comparisons at several other Nyquist frequencies (analogous to Fig. 2-9(h)). Exact equivalence is obtained in every case.[28] Note that the Nyquist frequency of 0.5 Hz (Fig. 2-10(a)) is below the frequency of the second mode at 0.87 Hz, so this mode is aliased to the incorrect frequency of 0.5 - (0.87 - 0.5) = 0.13 Hz. In Fig. 2-10(b), the Nyquist frequency of 0.667 Hz is midway between the two modal frequencies causing them to coalesce into a single peak in $H(z)$. If data with aliased modes are analyzed with ERA, the aliased (incorrect) frequencies are obtained. Aliasing must be eliminated (or minimized) during data acquisition using adequate sampling and/or low-pass filtering.

The next two report sections, Sections 2.3 and 2.4, derive ERA using a continuous state-space model formulation and using a discrete state-space model formulation, respectively. Data from the MATLAB 2-DOF example covered in Sections 2.1 and 2.2 are analyzed with the FORTRAN software described in Chapters 3+ of this User's Guide.

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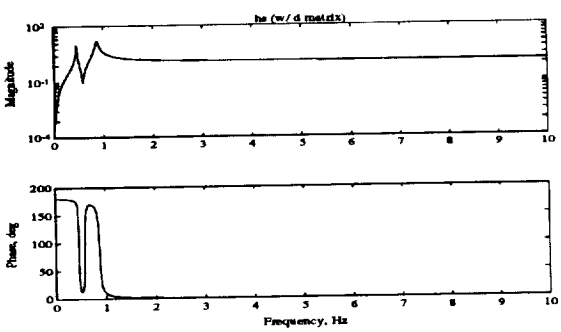
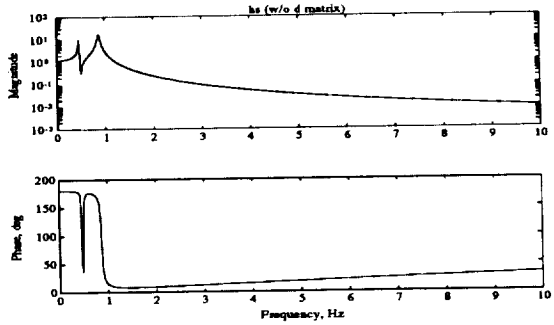
[26]Fig. 2-9 is generated with MATLAB file ERA$MATLAB:HZ_FROM_HS_AND_ZOH.M.

[27]Fig. 2-9(h) contains 2 curves: H(z) is a dashed line and the function derived from H(s) is a solid line. The 2 curves are indistinguishable.

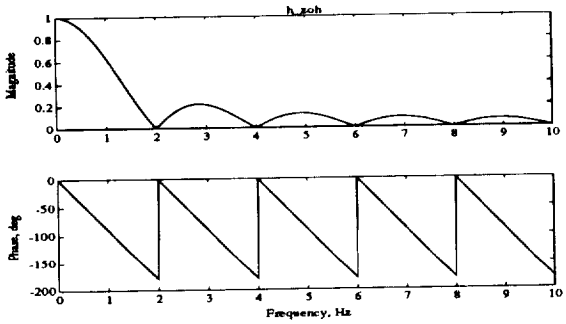
[28]Each plot in Fig. 2-10 contains 2 curves: H(z) is a dashed line and the function derived from H(s) is a solid line. The 2 curves are indistinguishable in all 4 plots.



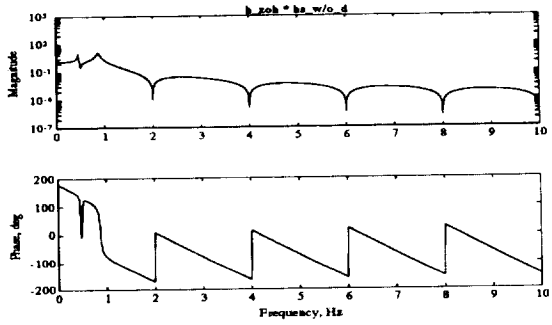
(a) H(s)



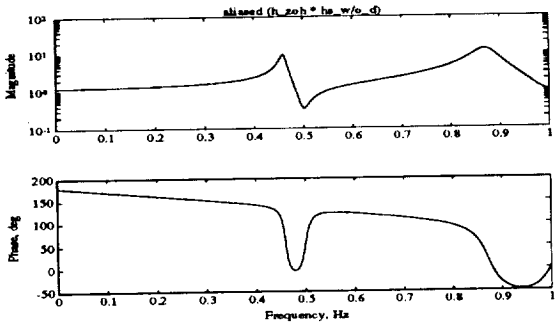
(b) H(s)_w/o_D



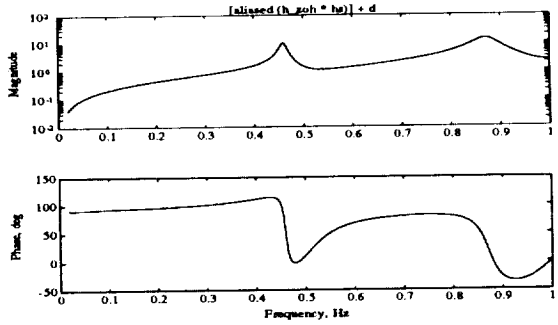
(c) ZOH



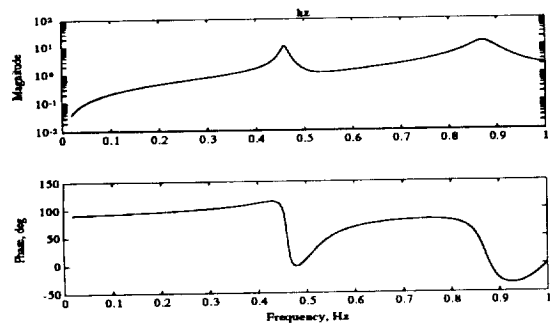
(d) Fig. (c) x Fig. (b)



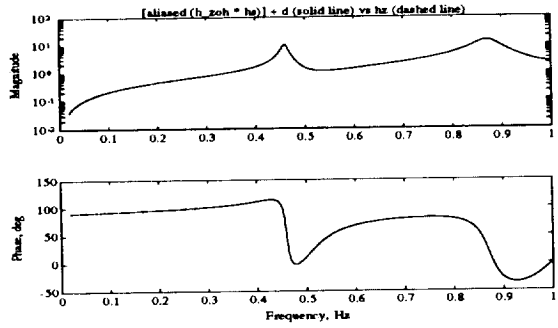
(e) Aliased Fig. (d)



(f) Fig. (e) + D

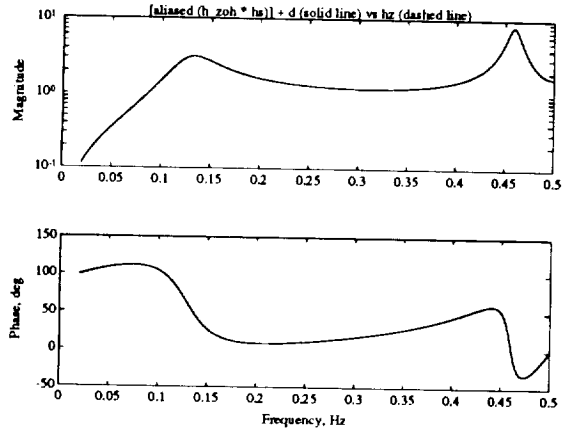


(g) H(z)

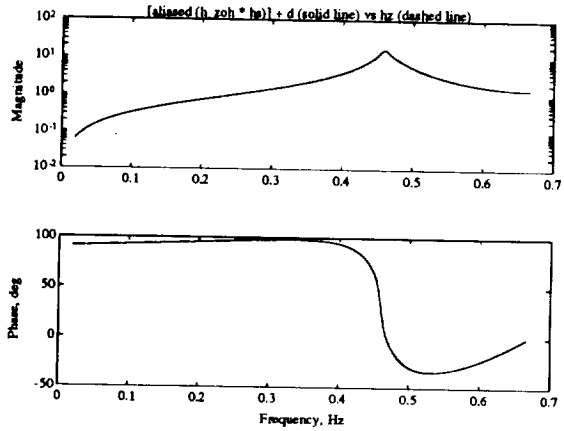


(h) Comparison of Figs. (f) & (g)

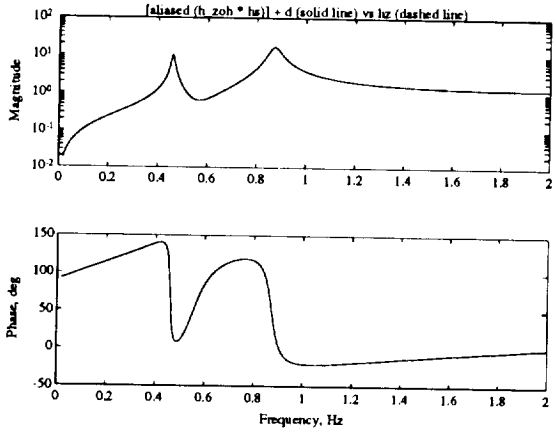
Fig. 2-9. Graphical Construction of $H_{a,11}(z)$ From $H_{a,11}(s)$ (Nyquist Frequency = 1 Hz)



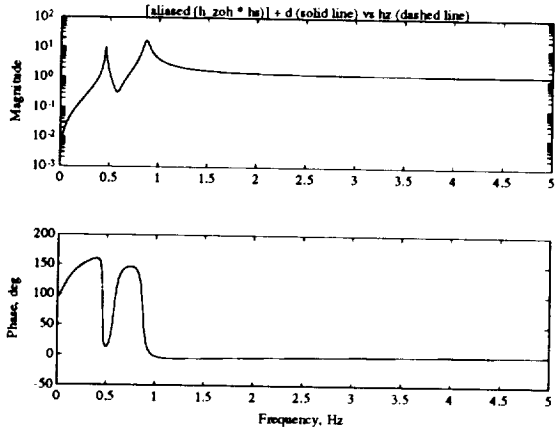
(a) Nyquist Frequency = 0.5 Hz



(b) Nyquist Frequency = 0.667 Hz



(c) Nyquist Frequency = 2 Hz



(d) Nyquist Frequency = 5 Hz

Fig. 2-10. Comparison of $H_{a,11}(z)$ and Function Derived From $H_{a,11}(s)$ Using Method of Fig. 2-9 at Other Nyquist Frequencies

2.3 ERA With a Continuous State-Space Model

Experimentally, frequency response functions of a continuous-time system, $H(s)|_{s=j\omega}$, are measured using the data-acquisition configuration shown in Fig. 2-1. Continuous, analog excitation and response signals, $u_1(t)$ and $y_1(t)$, are low-pass filtered (anti-aliasing filters) and then uniformly sampled to generate sequences $u_1(k)$ and $y_1(k)$. The anti-aliasing filters have very sharp attenuation rates, e.g., 96 dB/octave or greater. The sharp attenuation permits sampling rates as low as approximately 2.6 times the highest frequency of interest to be used. The selected combination of sampling rate and filter characteristics **guarantees alias-free data** in the bandwidth of interest (typically from 0 to 75% of the Nyquist frequency) by sufficiently attenuating all aliased frequency components in this bandwidth.[29] The input $u_1(t)$ is sufficiently rich to excite all modes in the bandwidth of interest. Multiple-input, burst-random excitation is often used in structural modal testing to obtain consistent data for multiple inputs while avoiding FFT leakage errors (Ref. 9).[30]

Note

Experimentally, s-domain FRFs identical to those obtained with random excitation described above are obtained using classical, steady-state sinusoidal excitation at each frequency (stepped sine dwell). This approach is seldom used in practice today, however, because it is usually much slower than using modern, random-excitation/FFT methods.

ERA uses impulse response functions (IRFs) to identify continuous state-space models. The IRF is the free response of the system to a unit impulse excitation ($u(t) = \delta(t)$, the Dirac delta function) applied at a particular input location to the system at rest. ERA typically uses IRFs for multiple input locations simultaneously in the analysis to efficiently identify closely spaced modes (ref. Section 10.4). Experimentally, IRFs are usually obtained by inverse Fourier transformation of $H(s)$ frequency response functions.

---

[29] An example of commercially available hardware with these characteristics is the ZONIC 7000 system used at NASA Langley.

[30] The terminology "consistent data" used in modal testing refers to multiple sets of data having identical eigenvalues and eigenvectors. That is, there are no changes of test-article dynamic characteristics (through mass loading, temperature variation, boundary condition changes, etc.) among various data sets. Inconsistent data can cause difficulties for multiple-input identification methods such as ERA that assume invariant dynamic characteristics among multiple data sets analyzed simultaneously.

2.3.1 Formulation of ERA With Continuous Model

An N-dimensional, linear, time-invariant dynamic system is represented by the state-variable equations:

$$\dot{x}(t) = A_c x(t) + Bu(t)$$
$$y(t) = Cx(t) + Du(t) \tag{2-14}$$

where x is an N-dimensional state vector, y is a p-dimensional response vector, u is a q-dimensional excitation vector, and A_c, B, C, and D are matrices of appropriate dimensions (Ref. 17).[31] A special solution to these equations is the impulse response function (IRF):[32]

$$Y(t) = Ce^{A_c t}B + D\delta(t) \tag{2-15}$$

for $t \geq 0$, where $\delta(t)$ is the Dirac delta function. The ith column of $Y(t)$ contains the free response of the system, with $x(0) = 0$, to a unit impulse excitation ($u(t) = \delta(t)$) applied at the ith input location at $t = 0$.

With sampled data ($t = k\Delta t, k = 0,1,2,\cdots$), this solution becomes:

$$Y(k) = CA^k B \qquad (p \times q) \tag{2-16}$$

where $A = e^{A_c \Delta t}$ is the state-transition matrix and Δt is the data sampling interval.[33]

The problem of system realization is as follows: Given a sequence of experimentally measured matrices $Y(k)$, for $k = 0,1,2,...$, construct a triplet $[A,B,C]$ such that Eq. 2-16 is satisfied as closely as possible. Note that $[A,B,C]$ is not unique since the set $\left[T^{-1}A_c T, T^{-1}B, CT\right]$, for any nonsingular matrix T, also satisfies the state-variable equations.

---

[31] A structure with m modes requires a state vector dimension, N, of (at least) $2m$. Each mode corresponds to a complex-conjugate pair of eigenvalues. B_c of Eq. 2-1 is renamed B to simplify notation in this section.

[32] $Y_c(t)$ of Eq. 2-2 is renamed $Y(t)$ to simplify notation in this section.

[33] The $D\delta(t)$ term of Eq. (2-15) can be ignored for modal identification purposes. If necessary, the D matrix can be calculated from ERA-identified mass-scaled mode shapes, Φ (generated with ERA post-processor program ERAP11, described in Section 3.15) using Eq. 2-9. Or it can be approximated from sampled IRF data (obtained by inverse Fourier transformation of FRFs) using the technique illustrated in Section 2.3.2 (Table 2-4). The approximation improves as Δt decreases. **Note**: The $D\delta(t)$ term is also ignored in MATLAB when IRFs are calculated with the IMPULSE function.

The ERA solution to the system realization problem begins with construction of "generalized Hankel matrices" $H_{rs}(k)$, k=0,1, consisting of r block rows and s block columns of time-shifted $Y(k)$ submatrices as follows:[34]

$$H_{rs}(k) = \begin{bmatrix} Y(k) & Y(k+1) & Y(k+2) & \cdots & Y(k+s-1) \\ Y(k+1) & Y(k+2) & Y(k+3) & \cdots & Y(k+s) \\ Y(k+2) & Y(k+3) & Y(k+4) & \cdots & Y(k+s+1) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Y(k+r-1) & Y(k+r) & Y(k+r+1) & \cdots & Y(k+r+s-2) \end{bmatrix}. \quad (2\text{-}17)$$

$H_{rs}(k)$ has a total of $n_r = p \cdot r$ rows and $n_c = q \cdot s$ columns, where $n_r, n_c \geq N$.[35]

By Eqs. 2-16 and 2-17,

$$H_{rs}(k) = VA^kW \quad (2\text{-}18)$$

where

$$V = \begin{bmatrix} C \\ CA \\ \vdots \\ CA^{r-1} \end{bmatrix} \text{ and } W = \begin{bmatrix} B & AB & \cdots & A^{s-1}B \end{bmatrix} \quad (2\text{-}19)$$

are generalized observability and controllability matrices, respectively. Parameters r and s are called the observability and controllability indices (Ref. 17). By construction of $H_{rs}(k)$, $\text{rank}(H_{rs}(k)) = \text{rank}(V) = \text{rank}(W) = N$.

Calculate the singular-value decomposition of $H_{rs}(0)$ (Ref. 21):

$$H_{rs}(0) = \underline{P}\,\underline{D}\,\underline{Q}^T \qquad (n_r \times n_c) \quad (2\text{-}20)$$

where

$$\underline{P}^T\underline{P} = I, \ \underline{Q}^T\underline{Q} = I \quad (2\text{-}21)$$

and

[34]The structure of $H_{rs}(k)$ is modified in practice as described in Appendix K.

[35]Theoretically, the minimum size of $H_{rs}(k)$ is $n_r, n_c = N$. The maximum "worst case" size of $H_{rs}(k)$ is $n_r = pN$ and $n_c = qN$. In practice, $n_r, n_c \geq 3N$ is typically used successfully. Guidelines for selecting the size of the generalized Hankel matrix with "nonideal" (experimental) data are given in Appendix I.

$$\underline{D} = \begin{bmatrix} d_1 & & & & & \\ & \ddots & & & & \\ & & d_N & & & \\ & & & d_{N+1} & & \\ & & & & \ddots & \\ & & & & & d_M \end{bmatrix} \tag{2-22}$$

is a diagonal matrix containing the ordered singular values, $d_1 \geq d_2 \geq \cdots \geq d_N > 0$,

with

$$d_{N+1} = d_{N+2} = \cdots = d_M = 0 \tag{2-23}$$

and $M = \min(n_r, n_c)$.

Let

$$D = \begin{bmatrix} d_1 & & \\ & \ddots & \\ & & d_N \end{bmatrix} \tag{2-24}$$

contain the N nonzero singular values of $\underline{D}$, and P and Q contain the N corresponding columns of $\underline{P}$ and $\underline{Q}$, respectively.

Then,

$$H_{rs}(0) = PDQ^T \tag{2-25}$$

and

$$P^T P = I, \; Q^T Q = I. \tag{2-26}$$

Using Eqs. 2-18 through 2-26, an Nth-order realization, [A,B,C], is now derived.

By Eqs. 2-18 and 2-25,

$$H_{rs}(0) = PDQ^T = (PD^{1/2})(D^{1/2}Q^T) = VW \tag{2-27}$$

so that

$$V = PD^{1/2} \text{ and } W = D^{1/2}Q^T \tag{2-28}$$

is a balanced decomposition of $H_{rs}(0)$.[36]

By Eqs. 2-18, 2-26 and 2-28,

$$\begin{aligned} VAW &= H_{rs}(1) \\ PD^{1/2} \cdot A \cdot D^{1/2}Q^T &= H_{rs}(1) \\ D^{1/2}AD^{1/2} &= P^T H_{rs}(1) Q \\ A &= D^{-1/2}P^T H_{rs}(1) Q D^{-1/2}. \end{aligned} \tag{2-29}$$

Let

$$E_p^T = \begin{bmatrix} I_p & 0_p & \cdots & 0_p \end{bmatrix} \text{ and } E_q^T = \begin{bmatrix} I_q & 0_q & \cdots & 0_q \end{bmatrix}. \tag{2-30}$$

Then, by Eqs. 2-17, 2-18, 2-28, 2-29, and 2-30,

$$\begin{aligned} Y(k) &= E_p^T \cdot H_{rs}(k) \cdot E_q \\ &= E_p^T \cdot VA^k W \cdot E_q \\ &= \left[E_p^T PD^{1/2}\right] \cdot \left[D^{-1/2}P^T H_{rs}(1) Q D^{-1/2}\right]^k \cdot \left[D^{1/2}Q^T E_q\right] \\ &\equiv CA^k B. \end{aligned}$$

Therefore, an Nth-order (minimum-order) ERA realization based on a continuous state-space model is as follows:

$$\begin{aligned} A &= D^{-1/2}P^T H_{rs}(1) Q D^{-1/2} && (N \times N) \\ B &= D^{1/2}Q^T E_q && (N \times q) \\ C &= E_p^T PD^{1/2} && (p \times N) \end{aligned} \tag{2-31}$$

[36]The decomposition of $H_{rs}(0)$ is clearly not unique. A realization with $V^T V = WW^T$ is an "internally balanced realization" (Ref. 17). By Eqs. 2-26 and 2-28, $V^T V = WW^T = D$.

Transform this realization to modal coordinates using the eigenvalues Z and eigenvector matrix Ψ of A:[37]

$$A' = \Psi^{-1} A \Psi = Z \quad (diagonal)$$

$$B' = \Psi^{-1} B \tag{2-32}$$

$$C' = C\Psi .$$

Structural modal damping rates, σ_i, and damped natural frequencies, ω_{di}, in rad/sec are the real and imaginary parts of the eigenvalues after transformation back to the continuous domain:[38]

$$s_i = \sigma_i \pm j\omega_{di} = \ln(z_i) / \Delta t . \tag{2-33}$$

Modal damping factors (fraction of critical damping) and damped natural frequencies in Hz are as follows:

$$\zeta_i = -\frac{\sigma_i}{\sqrt{\sigma_i^2 + \omega_{di}^2}} \qquad (\text{x } 100\ \%) \tag{2-34}$$

$$f_{di} = \frac{\omega_{di}}{2\pi} . \tag{2-35}$$

Modal participation factors and mode shapes are the corresponding rows of B' and columns of C', respectively.

Some modal parameters obtained by this approach are inaccurate due to measurement noise, nonlinearity, unmeasured disturbances, etc. Various "accuracy indicators" are used to assess the relative accuracy of the results. See Section 2.6.

With ideal data, $H_{rs}(0)$ has exactly N nonzero singular values. In practice, however, engineering judgment is normally necessary to select an "appropriate" value of n, the number of "significant" singular values. Often, n is incremented over a range of values and the corresponding modal parameters and accuracy indicators compared.[39]

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[37]It is not necessary to form the $\Psi^{-1} A \Psi$ matrix product. $A' = Z$, the eigenvalues of A.

[38]Section 10.7 discusses the nonuniqueness of Eq. 2-33.

[39]Section 3.10 demonstrates this feature of the software (parameter LOOPOP=1). Appendix J describes the logic used otherwise for singular-value truncation. The matrix $H_n(0)$ which minimizes $\|H - H_{rs}(0)\|_F$ (and $\|H - H_{rs}(0)\|_2$) over all $n_r \times n_c$ matrices H of rank less than or equal to n is $H_n(0) = P_n D_n Q_n^T$, where D_n contains the n largest singular values of $H_{rs}(0)$ and P_n and Q_n contain

The D matrix of Eq. 2-9 can be calculated from ERA-identified mass-scaled mode shapes, Φ.[40] Alternatively, the D matrix can be approximated from sampled IRF data (obtained by inverse Fourier transformation of FRFs) using the technique illustrated in Section 2.3.2 (Table 2-4). The approximation improves as Δt decreases.

2.3.2 ERA Results For MATLAB 2-DOF Problem With Continuous Model

Impulse response functions (IRFs) for ERA analysis are created with MATLAB by two different methods for comparison purposes. The first method is direct simulation using the continuous state-space model, Eq. 2-14. A very short integration interval (0.005 sec) ensures close approximation of a continuous system. Unit impulse excitation (magnitude x duration = 1.0) is applied to each of the two inputs individually, and corresponding responses are calculated using the MATLAB LSIM function.[41] The second method of creating IRFs is by inverse Fourier transformation (IFFT) of $H(s)$ frequency response functions (FRFs). The FRFs are generated using the MATLAB BODE function.

Figs. 2-11 and 2-12 compare h_{11} IRFs obtained by these two methods for D/F and A/F data, respectively.[42] The two functions in each figure are essentially identical except for the A/F data at $t = 0$. This difference at $t = 0$ occurs because the theoretical initial impulse response of a continuous system with nonzero D matrix is infinite ($h_{a,11}(0) = CB + D\delta(0)$). A large value is obtained in the time simulation (1000.0). Using the IFFT, on the hand, a value approximately equal to $D/\Delta t$ is obtained (3.9995).[43] **Table 2-2** lists the initial value of each IRF, $h_{kl}(0), k = 1,2; l = 1,2$, for the 4 cases studied. Note that all off-diagonal terms of D for A/F data are zero ($D_a = M^{-1}$, Eq. 2-7).

	D/F LSIM	D/F IFFT	A/F LSIM	A/F IFFT
$h_{11}(0)$	0.0	3.38E-2	1000.0	3.9995
$h_{12}(0) = h_{21}(0)$	0.0	-1.88E-4	0.0	2.69E-1
$h_{22}(0)$	0.0	1.78E-2	533.3	2.3838

Table 2-2. Initial Values of the IRFs, $h_{kl}(0), k = 1,2; l = 1,2$

---

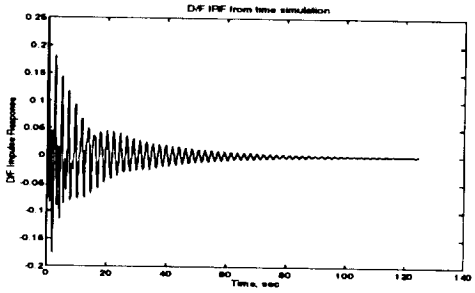
the n corresponding singular vectors (Ref. 21, p. 330). Thus, $H_n(0)$ provides the best nth-order approximation of $H_{rs}(0)$ in a least-squares sense.

[40] Φ is obtained with ERA post-processor program ERAP11, described in Section 3.15.

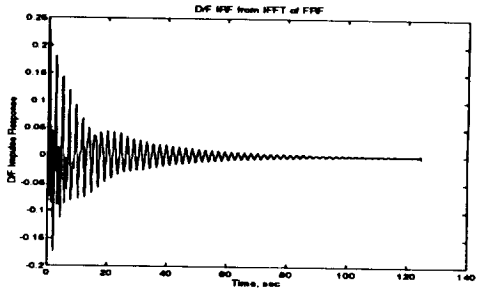
[41] A version of LSIM named LSIM_FOH is used that interpolates the input using a first-order hold.

[42] Figs. 2-11 and 2-12 are generated with MATLAB files ERA$MATLAB:IRFS_DF_THEORY.M and IRFS_AF_THEORY.M, respectively.

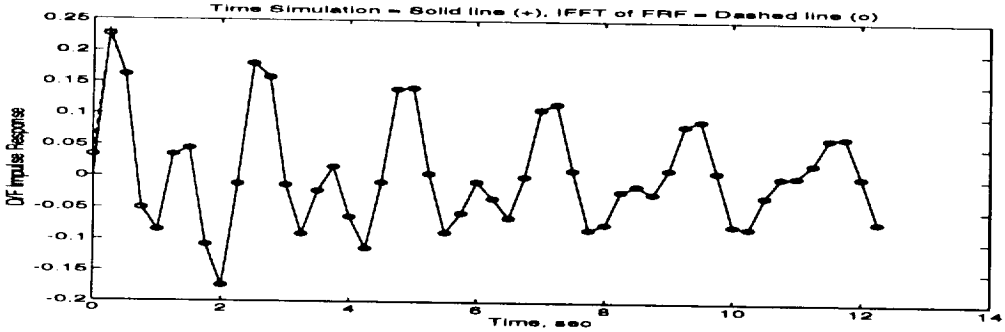
[43] $D_a(1,1)$ estimated as $h_{a,11}(0) \cdot \Delta t$ from IFFT data for various values of Δt are presented in Table 2-4. The approximation improves as Δt decreases.



(a) Time Simulation w/ Cont. Model (Integration Δt = 0.005 sec)

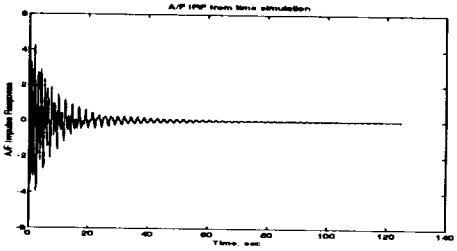


(b) IFFT of FRF (FRF Range: 0 - 2 Hz)

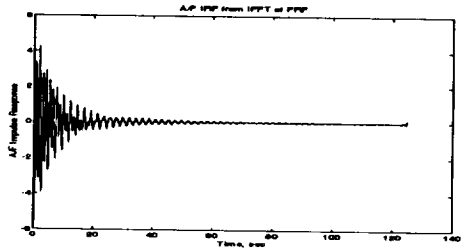


(c) Comparison of First 50 Data Samples

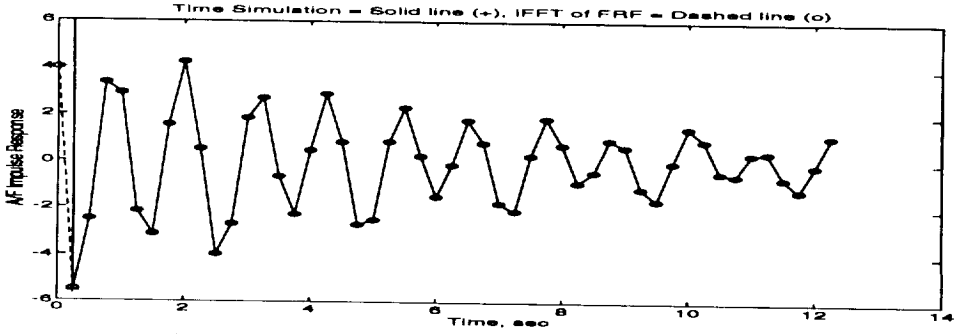
Fig. 2-11. Comparison of D/F IRFs: Time Simulation vs IFFT of FRF



(a) Time Simulation w/ Cont. Model (Integration Δt = 0.005 sec)



(b) IFFT of FRF (FRF Range: 0 - 2 Hz)



(c) Comparison of First 50 Data Samples

Fig. 2-12. Comparison of A/F IRFs: Time Simulation vs IFFT of FRF

For completeness, **Figs. 2-13 and 2-14** show all 4 IRFs and FRFs with D/F and A/F data, respectively. The first column in each figure shows functions for Input 1 and the second column for Input 2. The first row in each figure shows functions for Output 1 and the second row for Output 2. By Maxwell's Reciprocity Theorem, $H_{12} = H_{21}$. The IRFs are generated by IFFT of the FRFs.

All 4 data sets are now analyzed with the ERA software described in Chapters 3+ of this User's Guide.[44] All VAX files used in the analysis are stored in directory ERA$2DOF. The ERA "User Input files" are named IRF_DF_LSIM.ERA, IRF_DF_IFFT.ERA, IRF_AF_LSIM.ERA, and IRF_AF_IFFT.ERA. Each analysis uses a Hankel matrix size of 20 x 20 ($n_r = n_c = 20$, Eq. 2-17).

Fig. 2-15 shows the singular values of $H_{rs}(0)$, $d_1 \geq d_2 \geq \cdots \geq d_M \geq 0$. The shaded bars represent those singular values retained in the analysis ($d_1 \geq d_2 \geq \cdots \geq d_n > 0$). Singular-value truncation is based on the numerical rank of $H_{rs}(0)$, selected by specifying software parameter NUMRNK = 1. This truncation method is appropriate when analyzing noise-free simulated data (ref. Chapter 6 and discussion of Tape50 output file in Section 3.6).

Note that although this is an ideal, noise-free, 4th-order system (2 modes), more than 4 singular values are nonzero in every case. With D/F LSIM data, a drop of 60 dB (1000 in magnitude) occurs after the 4th singular value, indicating that these data are closely represented by a 4th-order model. Nonzero values of the 5th and 6th singular values are caused by approximation in the time simulation process. With A/F LSIM data, however, there are 6 significant singular values. Singular values 5 and 6 increase in this case because of the large values of $h_{11}(0)$ and $h_{22}(0)$.[45] These large initial data values in the driving-point IRFs are approximated by ERA with 2 additional real eigenvalues (real exponential functions beginning at $t = 0$).[46] With both the D/F and A/F IFFT data, the singular values attenuate at approximately a uniform rate, providing no obvious "best" singular-value truncation points.[47] This is the typical situation when analyzing experimental IRF data.[48] The ERA software retained 12 and 13 singular values in the D/F and A/F IFFT analyses, respectively. In all 4 analyses, however, ERA identifies exactly 2 structural modes. The

[44]This chapter (Chapter 2) does **not** provide instructions for using the software.

[45]Recall that the $D\delta(t)$ term of Eq. 2-15 is ignored in deriving Eq. 2-16. Note that all off-diagonal terms of D for A/F data are zero ($D_a = M^{-1}$, Eq. 2-7). Therefore, Eq. 2-16 is satisfied exactly for all IRFs except A/F driving-point IRFs ($h_{a,kl}(t), k = l$).

[46]An optional software parameter, MODELC = 1 or 2, can be used to zero the first data point in each IRF before performing the ERA analysis. This is normally not necessary for modal identification purposes.

[47]The largest singular-value drops in the IFFT data do occur after 4 and 6 singular values, however, corresponding to the much-larger drops in the corresponding LSIM data.

[48]Except perhaps for some trivially simple test articles.

remaining identified eigenvalues are real eigenvalues that model the distortions discussed above caused by the time simulation and Fourier transformation processes.

Table 2-3 compares the true values of the modal parameters (from Table 2-1) with the ERA identification results for all 4 cases. All modal parameters are identified exactly except for the mass-scaled mode shapes. For Mass-Scaled Mode 1, the maximum error is 0.24%. For Mass-Scaled Mode 2, the maximum error is 0.025%.

The modal parameters given in Table 2-3 provide a complete state-space model based on Eq. 2-9.[49] The D matrix of Eq. 2-9 is calculated from ERA-identified mass-scaled mode shapes, Φ.[50] Alternatively, it can be approximated from sampled IRF data (obtained by inverse Fourier transformation of FRFs) using the technique illustrated in **Table 2-4**. The approximation improves as Δt decreases.

[49] $\omega_{ni} = 2\pi f_{di} / \sqrt{1-\zeta_i^2}$.

[50] The validity of $\underline{D}_a = \Phi\Phi^T = M^{-1}$ depends on the orthogonality of modes, $\Phi^T M \Phi = I$. With experimental data, orthogonality is only approximately achieved. Φ is obtained with ERA post-processor program ERAP11, described in Section 3.15.

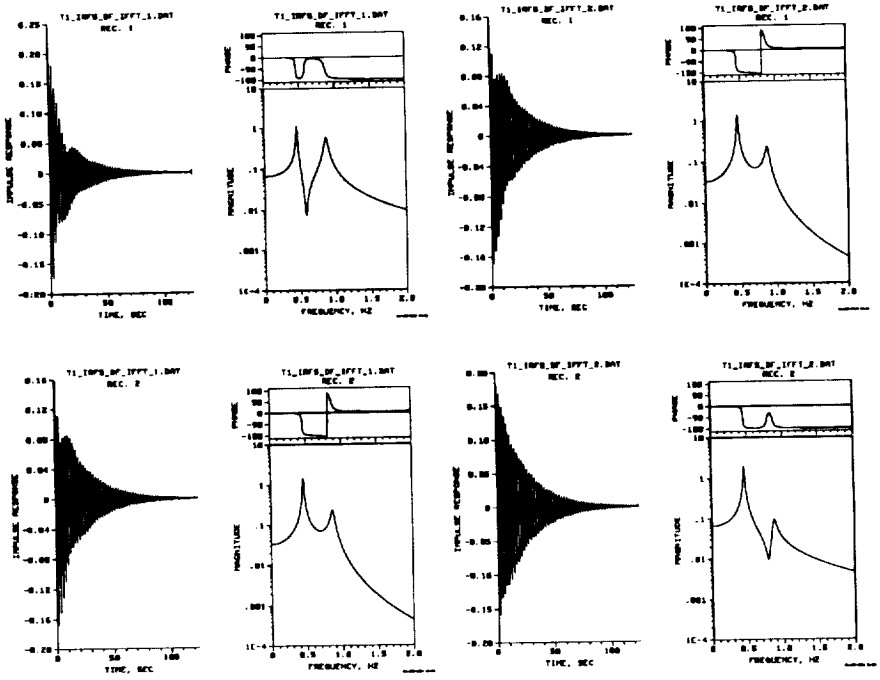


Fig. 2-13. D/F IRFs and FRFs: 2 Inputs (Cols), 2 Outputs (Rows)

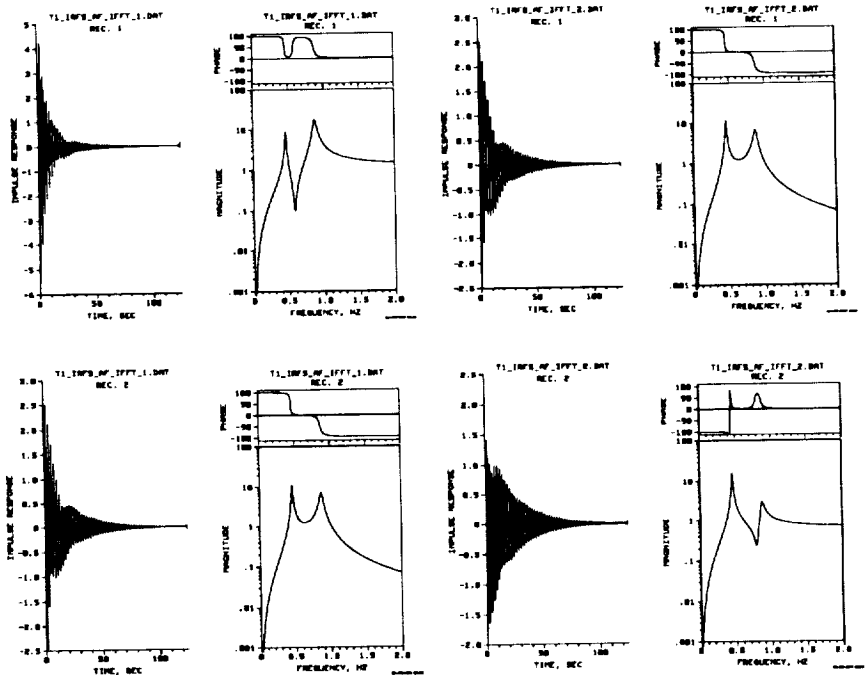
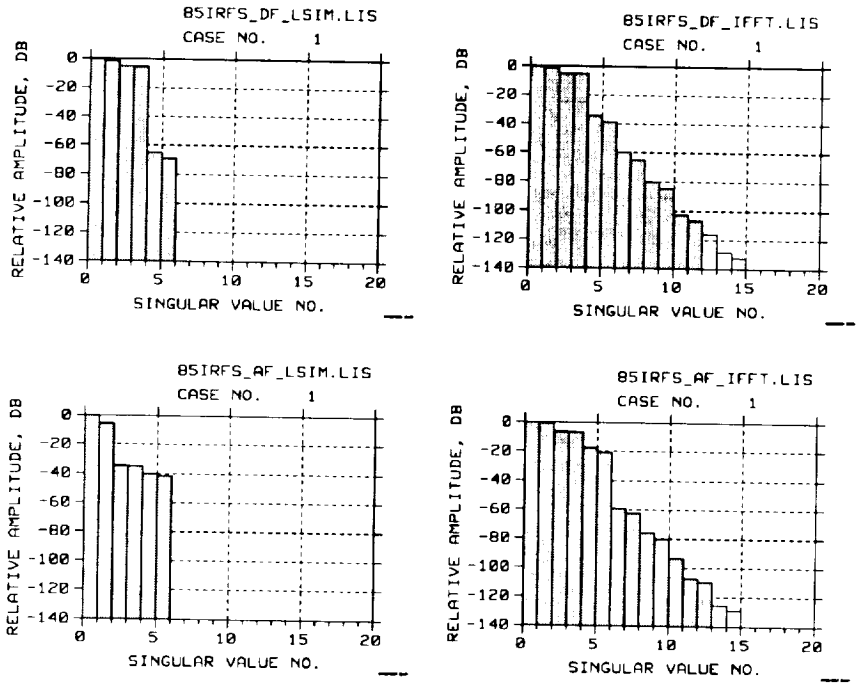


Fig. 2-14. A/F IRFs and FRFs: 2 Inputs (Cols), 2 Outputs (Rows)



Upper Left: Using D/F LSIM Data **Upper Right: Using D/F IFFT Data**
Lower Left: Using A/F LSIM Data **Lower Right: Using A/F IFFT Data**

Fig. 2-15. Singular Values From ERA Analysis of IRFs

	True Values	D/F LSIM	D/F IFFT	A/F LSIM	A/F IFFT
f_d, Hz	0.4594 0.8714	0.4594 0.8714	0.4594 0.8714	0.4594 0.8714	0.4594 0.8714
ζ, %	1.443 2.739	1.443 2.739	1.443 2.739	1.443 2.739	1.443 2.739
Ampl.-Scaled Mode 1	75.00 100.00	75.00 100.00	75.00 100.00	75.00 100.00	75.00 100.00
Ampl.-Scaled Mode 2	100.00 -40.00	100.00 -40.00	100.00 -40.00	100.00 -40.00	100.00 -40.00
Mass-Scaled Mode 1	0.5371 0.7161	0.5371 0.7161	0.5358 0.7144	0.5371 0.7161	0.5358 0.7144
Mass-Scaled Mode 2	0.9806 -0.3922	0.9806 -0.3923	0.9806 -0.3922	0.9806 -0.3923	0.9806 -0.3922

Table 2-3. ERA Results For MATLAB 2-DOF Problem Using Continuous-Time Model (IRFs)

Sampling Interval, sec Δt	Nyquist Frequency, Hz $(=\frac{1}{2\Delta t})$	$D_a(1,1) = h_{a,11}(0) \cdot \Delta t$	Exact $D_a(1,1)$
0.50	1	-0.0033	1.250
0.33	1.5	0.801	1.250
0.25	2	1.0	1.250
0.125	4	1.180	1.250
0.0625	8	1.228	1.250
0.03125	16	1.242	1.250

Table 2-4. $D_a(1,1) = h_{a,11}(0) \cdot \Delta t$ **For Various Values of** Δt

2.4 ERA With a Discrete State-Space Model

The vibration of structures is a continuous-time process governed by differential equations and continuous state-space models. However, if excitation is applied using zero-order hold (zoh) devices,[51] finite-dimensional, continuous-time linear systems are represented exactly at the sample times by difference equations and discrete state-space models (Ref. 19). Control engineers usually use a discrete model representation for system identification (system realization) purposes. Fig. 2-2 shows the customary hardware configuration.

A discrete-time state-space model can exactly predict the response sequence, $y(k)$, for all possible input sequences, $u(k)$, at any user-selected sampling rate.[52] However, the model is developed at a particular data sampling rate and cannot, in general, be uniquely translated to other sampling rates. The discrete-time model is an exact input-output map, in contrast to the "bandlimited" continuous state-space model described in Section 2.3, **because the entire FRF of each mode ($-\infty \le f \le \infty$) aliases into the frequency range from 0 Hz to the Nyquist frequency of $\frac{1}{2\Delta t}$ Hz, where Δt is the sampling interval** (ref. Figs. 2-8 and 2-9).[53] However, in control applications the response of modes with natural frequencies above the Nyquist frequency must be minimized. Therefore, a Nyquist frequency significantly higher than the highest natural frequency of interest is normally used. Also, a low-order, analog low-pass filter is often placed between the response sensor and sampler to reduce the (measured) response of high-frequency modes further.[54]

ERA uses pulse response functions (PRFs)[55] to identify discrete models. The PRF is the free response to a unit-amplitude excitation applied at an input location for one data-sampling interval. ERA typically uses PRFs for multiple input locations simultaneously in the analysis to efficiently identify closely spaced modes (ref. Section 10.4).

Experimentally, PRFs can be obtained in 3 different ways:

1) by inverse Fourier transformation of $H(z)$ frequency response functions
2) by direct measurement of the free response due to a unit pulse excitation
3) using input-output time histories and the OKID procedure (Ref. 16).

---

[51] A zoh generates a constant output over a selected sampling interval.

[52] Exact prediction of response with a discrete-time model requires that the system be finite-dimensional (finite number of modes) which is only approximated in practice with structures.

[53] Bandlimited FRFs (IRFs) are used to identify continuous state-space models causing them to be valid, at best, only in that frequency range. Using bandlimited (truncated) FRFs in ERA generally causes negligible errors in the identified modal parameters within this frequency range except for modes near the upper and lower frequency limits (ref. Fig. 3-5).

[54] This combination of oversampling and low-pass filtering causes the discrete-model FRFs to approximate continuous-model FRFs in the frequency range of interest.

[55] Also called Markov parameters.

2.4.1 Formulation of ERA With Discrete Model

An N-dimensional, linear, time-invariant dynamic system is represented by the state-variable equations:

$$\begin{aligned} x(k+1) &= Ax(k) + Bu(k) \\ y(k) &= Cx(k) + Du(k) \end{aligned} \tag{2-36}$$

where x is an N-dimensional state vector, y is a p-dimensional response vector, u is a q-dimensional excitation vector, and A, B, C, and D are matrices of appropriate dimensions (Ref. 17).[56] A special solution to these equations is the pulse response function (PRF):

$$Y(k) = \begin{cases} D & for\ k = 0 \\ CA^{k-1}B & for\ k = 1,2,3,\cdots \end{cases} \tag{2-37}$$

The ith column of $Y(k)$ contains the free response of the system, with $x(0) = 0$, to a unit-amplitude pulse excitation ($u(0) = 1$ and $u(k) = 0$ for $k \geq 1$) applied at the ith input location at $t = 0$.

The problem of system realization is as follows: Given a sequence of experimentally measured matrices $Y(k)$, for $k = 0,1,2,...$, construct a quadruplet $[A,B,C,D]$ such that Eq. 2-37 is satisfied as closely as possible. Note that $[A,B,C,D]$ is not unique since the set $\left[T^{-1}AT, T^{-1}B, CT, D\right]$, for any nonsingular matrix T, also satisfies the state-variable equations.

In Section 2.3.1, the sampled impulse response function (IRF) of a continuous system (Eq. 2-16) was shown to be

$$Y(k) = CA^kB_c \qquad for\ k \geq 0 \tag{2-38}$$

where $A = e^{A_c \Delta t}$ is the state-transition matrix, and Δt is the data sampling interval.

Note the similarity of Eqs. 2-37 and 2-38. The same ERA algorithm is used to identify either $[A_c,B_c,C]$ or $[A,B,C,D]$.[57] The only difference is that the analysis of IRFs begins at the first data point, $Y(0)$, whereas analysis of

[56] A structure with m modes requires a state vector dimension, N, of (at least) $2m$. Each mode corresponds to a complex-conjugate pair of eigenvalues.

[57] With IRFs, A is obtained from the ERA analysis based on Eq. 2-38. A_c (diagonalized) can then be calculated from the eigenvalues of A and Δt. It is unnecessary, however, to calculate A_c to identify modal parameters.

PRFs begins at the second data point, $Y(1)$, with the first data point, $Y(0)$, set equal to D.

Thus, the ERA solution to the system realization problem with a discrete state-space model is identical to that presented in Section 2.3.1 for a continuous state-space model except that the data sequence, $Y(k)$, is shifted in time by 1 data sample.

Therefore, an Nth-order (minimum-order) ERA realization based on a discrete state-space model is as follows:

$$\begin{aligned} A &= D^{-1/2} P^T H_{rs}(2) Q D^{-1/2} && (N \times N) \\ B &= D^{1/2} Q^T E_q && (N \times q) \\ C &= E_p{}^T P D^{1/2} && (p \times N) \\ D &= Y(0) && (p \times q) \end{aligned} \qquad (2\text{-}39)$$

where

$$H_{rs}(1) = P D Q^T \qquad (n_r \times n_c) \qquad (2\text{-}40)$$

is the matrix decomposed with singular-value decomposition. See Section 2.3.1 for derivation details.

Transform this realization to modal coordinates using the eigenvalues Z and eigenvector matrix Ψ of A:[58]

$$\begin{aligned} A' &= \Psi^{-1} A \Psi = Z \quad (diagonal) \\ B' &= \Psi^{-1} B \\ C' &= C \Psi \\ D' &= D \end{aligned} \qquad (2\text{-}41)$$

[58]It is not necessary to form the $\Psi^{-1} A \Psi$ matrix product. $A' = Z$, the eigenvalues of A.

Structural modal damping rates, σ_i, and damped natural frequencies, ω_{di}, in rad/sec are the real and imaginary parts of the eigenvalues after transformation to the continuous domain:

$$s_i = \sigma_i \pm j\omega_{di} = \ln(z_i) / \Delta t \tag{2-42}$$

where Δt is the data sampling interval.

Modal damping factors (fraction of critical damping) and damped natural frequencies in Hz are as follows:

$$\zeta_i = -\frac{\sigma_i}{\sqrt{\sigma_i^2 + \omega_{di}^2}} \quad (\text{x } 100\ \%) \tag{2-43}$$

$$f_{di} = \frac{\omega_{di}}{2\pi}. \tag{2-44}$$

Modal participation factors and mode shapes are the corresponding rows of B' and columns of C', respectively.

Some modal parameters obtained by this approach are inaccurate due to measurement noise, nonlinearity, unmeasured disturbances, etc. Various "accuracy indicators" are used to assess the relative accuracy of the results. See Section 2.6.

With ideal data, $H_{rs}(1)$ has exactly N nonzero singular values. In practice, however, engineering judgment is normally necessary to select an "appropriate" value of n, the number of "significant" singular values. Often, n is incremented over a range of values and the corresponding modal parameters and accuracy indicators compared.[59]

When ERA identifies a discrete state-space model for control design, modal parameters are typically <u>not</u> of interest. The end product of the analysis is the $[A,B,C,D]$ model, Eq. 2-39. Model accuracy is evaluated by comparing measured

[59]Section 3.10 demonstrates this feature of the software (parameter LOOPOP=1). Appendix J describes the logic used otherwise for singular-value truncation. The matrix $H_n(1)$ which minimizes $\|H - H_{rs}(1)\|_F$ (and $\|H - H_{rs}(1)\|_2$) over all $n_r \times n_c$ matrices H of rank less than or equal to n is $H_n(1) = P_n D_n Q_n^T$, where D_n contains the n largest singular values of $H_{rs}(1)$ and P_n and Q_n contain the n corresponding singular vectors (Ref. 21, p. 330). Thus, $H_n(1)$ provides the best nth-order approximation of $H_{rs}(1)$ in a least-squares sense.

dynamic responses with corresponding model predictions.[60] For example, predicted PRFs of the model are calculated as follows:

$$\hat{Y}(k) = \begin{cases} D & for\ k = 0 \\ CA^{k-1}B & for\ k = 1,2,3,\cdots \end{cases} \qquad (2\text{-}45)$$

using the identified $[A, B, C, D]$ matrices. These predictions are compared with the measured PRFs, $Y(k)$, that were analyzed by ERA to obtain the model.

2.4.2 ERA Results For MATLAB 2-DOF Problem With Discrete Model

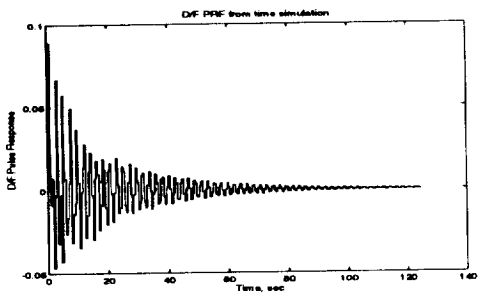
Pulse response functions (PRFs) for ERA analysis are created with MATLAB by three different methods for comparison purposes. The first method is direct simulation using the discrete state-space model, Eq. 2-36. Unit pulse excitation is applied to each of the two inputs individually, and corresponding responses are calculated using the MATLAB DLSIM function. The second method of creating PRFs is by inverse Fourier transformation (IFFT) of $H(z)$ frequency response functions (FRFs). The FRFs are generated using the MATLAB DBODE function. The third method is time-domain processing of general input-output data using the "Observer/Kalman filter identification (OKID)" technique (Ref. 22).

Figs. 2-16 and 2-17 compare h_{11} PRFs obtained by the DLSIM and IFFT methods for D/F and A/F data, respectively.[61] The two functions in each figure are essentially identical. In contrast to the approximate equivalence shown previously in Figs. 2-11 and 2-12 for a continuous-time model, the equivalence of PRFs and the IFFT of $H(z)$ FRFs for a discrete-time model is exact. This occurs because only a bandlimited segment of $H(s)$ can be inverse-Fourier-transformed numerically (the complete $H(s)$ extends from $-\infty \le f \le +\infty$), whereas the complete $H(z)$ function lies entirely between 0 and $\frac{1}{2\Delta t}$ Hz (the Nyquist frequency), where Δt is the data sampling interval.

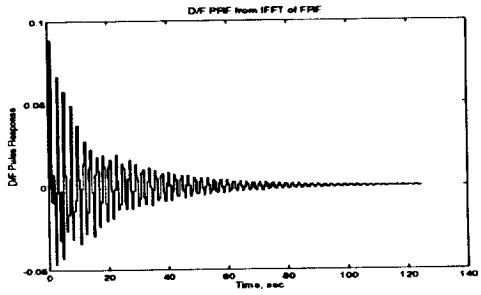
---

[60]Good agreement of measured and predicted responses is a necessary, but not sufficient, condition for accurate modal parameters.

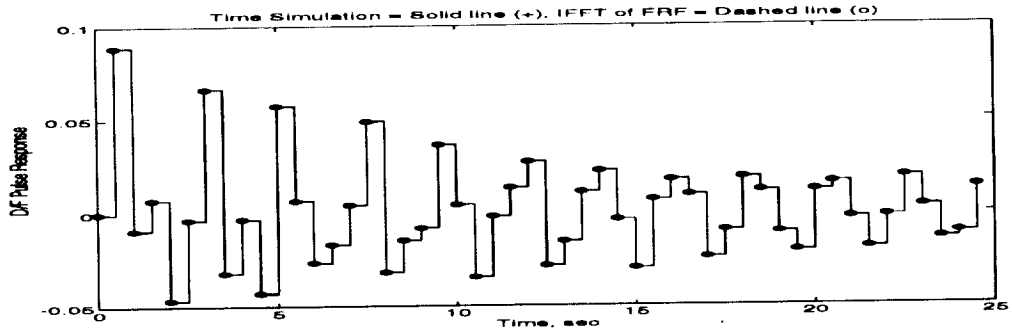
[61]Figs. 2-16 and 2-17 are generated with MATLAB files ERA$MATLAB:PRFS_DF_THEORY.M and PRFS_AF_THEORY.M, respectively. **Note**: Input-output time histories of a discrete-time system are customarily plotted as "staircase" functions as in Figs. 2-16 and 2-17. For excitation implemented with a zero-order hold, the input staircase function represents the precise, continuous time history applied to the system.



(a) Time Simulation Using Discrete Model

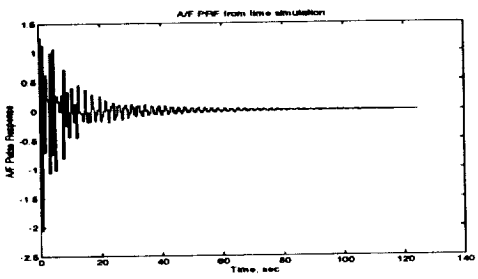


IFFT of FRF
(Nyquist Frequency: 1 Hz)

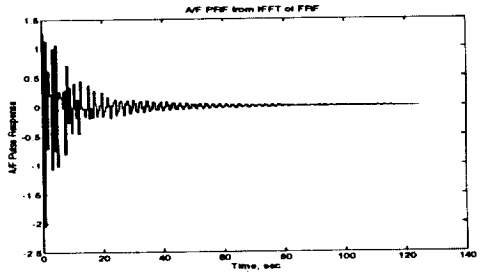


(c) Comparison of First 50 Data Samples

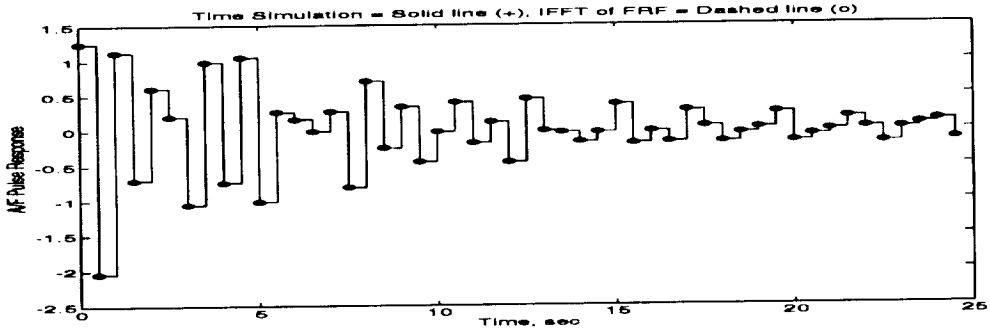
Fig. 2-16. Comparison of D/F PRFs: Time Simulation vs IFFT of FRF



(a) Time Simulation Using Discrete Model



IFFT of FRF
(Nyquist Frequency: 1 Hz)



(c) Comparison of First 50 Data Samples

Fig. 2-17. Comparison of A/F PRFs: Time Simulation vs IFFT of FRF

Figs. 2-18 and 2-19 compare h_{11} PRFs obtained by the DLSIM and OKID methods for D/F data.[62] (Results for A/F data are similar and are not shown.[63]) The OKID results shown in Fig. 2-18 are for the 2-DOF system **with** initial conditions, and those shown in Fig. 2-19 are for the 2-DOF system **without** initial conditions. Excellent equivalence with the DLSIM results is obtained using OKID for the system without initial conditions at all 3 data lengths (50, 100, and 200 data points)[64]. For the system with initial conditions, however, appreciable OKID errors occur, particularly using only 50 data points. The equivalence of OKID and DLSIM (true PRF) results with initial conditions improves as the data length increases. Note in Figs. 2-18(b) and 2-18(c) that the OKID errors are largest near the beginning of the functions. The effects of the transient response due to nonzero initial conditions are greatest in this region. All of the OKID results are obtained using 2-input, 2-output data with $p = 5$. The OKID parameter p (the number of observer Markov parameters) must be greater than or equal to the order of the system (4) divided by the number of outputs (2).

For completeness, **Figs. 2-20 and 2-21** show all 4 PRFs and FRFs with D/F and A/F data, respectively. The first column in each figure shows functions for Input 1 and the second column for Input 2. The first row in each figure shows functions for Output 1 and the second row for Output 2. By Maxwell's Reciprocity Theorem, $H_{12} = H_{21}$. The PRFs are generated by IFFT of the FRFs.

The DLSIM and OKID data sets are now analyzed with the ERA software described in Chapters 3+ of this User's Guide.[65] All VAX files used in the analysis are stored in directory ERA$2DOF. The ERA "User Input files" are named PRF_DF_DLSIM.ERA, PRF_DF_OKID.ERA, PRF_AF_DLSIM.ERA, and PRF_AF_OKID.ERA. Each analysis uses a Hankel matrix size of 20 x 20 ($n_r = n_c = 20$, Eq. 2-17).[66]

---

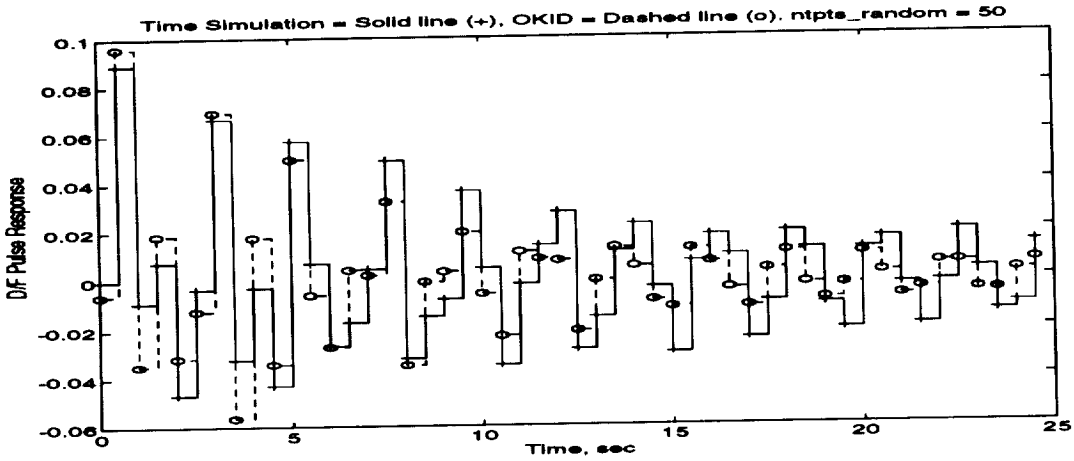
[62]Figs. 2-18 and 2-19 are generated with MATLAB file ERA$MATLAB:OKID_PRFS_DF_THEORY.M.

[63]Results for A/F data can be generated with MATLAB file ERA$MATLAB:OKID_PRFS_AF_THEORY.M.

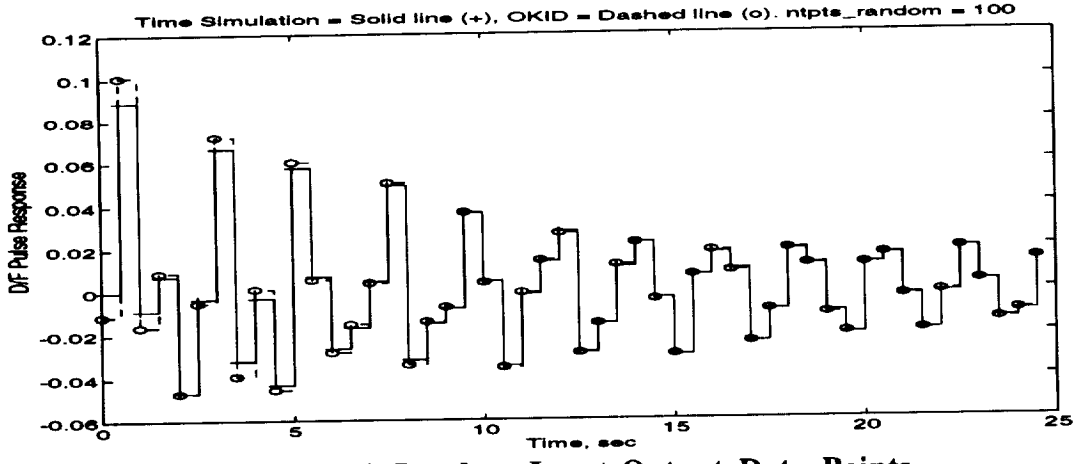
[64]Excellent equivalence (max. error approx. 1E-15) is obtained without initial conditions using data lengths as short as 16 input-output data points.

[65]Instructions for using the software are **not** provided in this chapter (Chapter 2). The IFFT data set was also analyzed with ERA and the results are essentially identical to those for the LSIM data set. The OKID data set analyzed with ERA is generated with initial conditions using 200 data points.

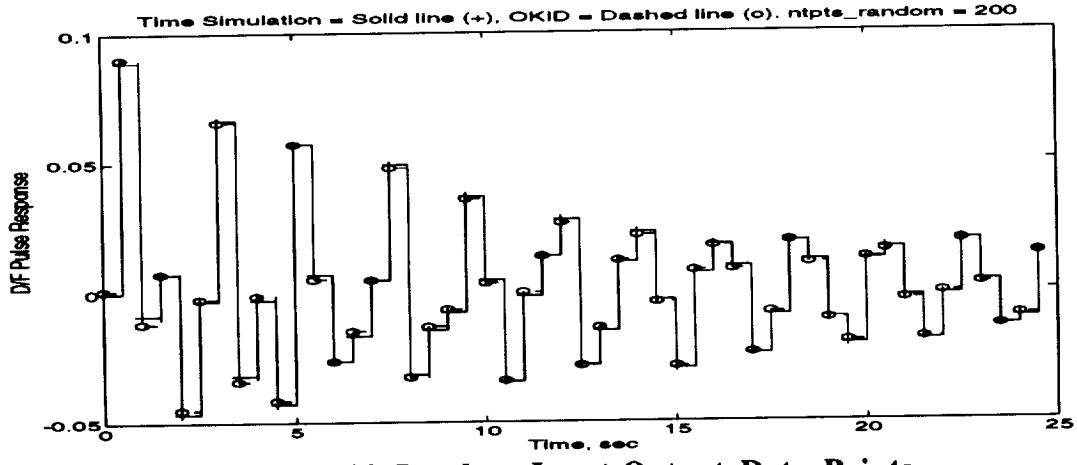
[66]A discrete model representation is selected by specifying parameter MODELD = 1 or 2. See Chapter 6 for a description of all software parameters.



(a) Using 50 Random Input-Output Data Points

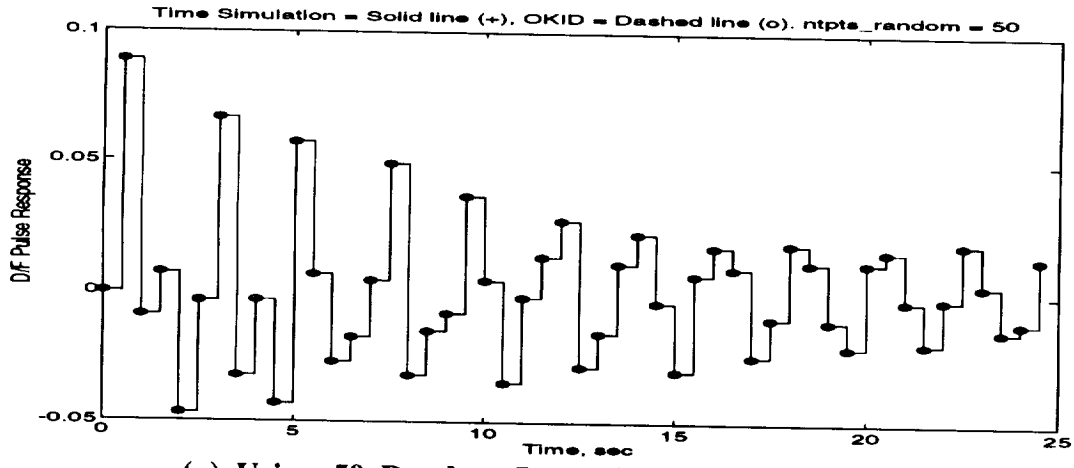


(b) Using 100 Random Input-Output Data Points

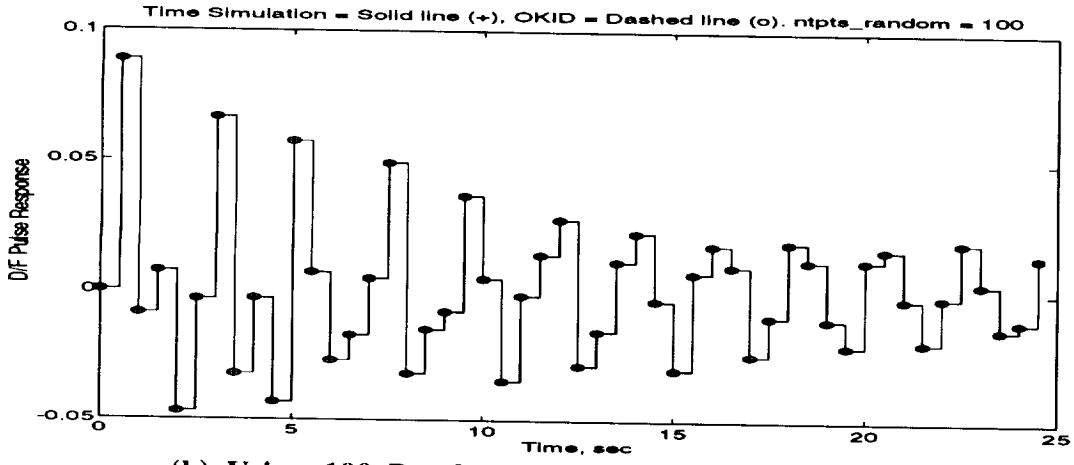


(c) Using 200 Random Input-Output Data Points

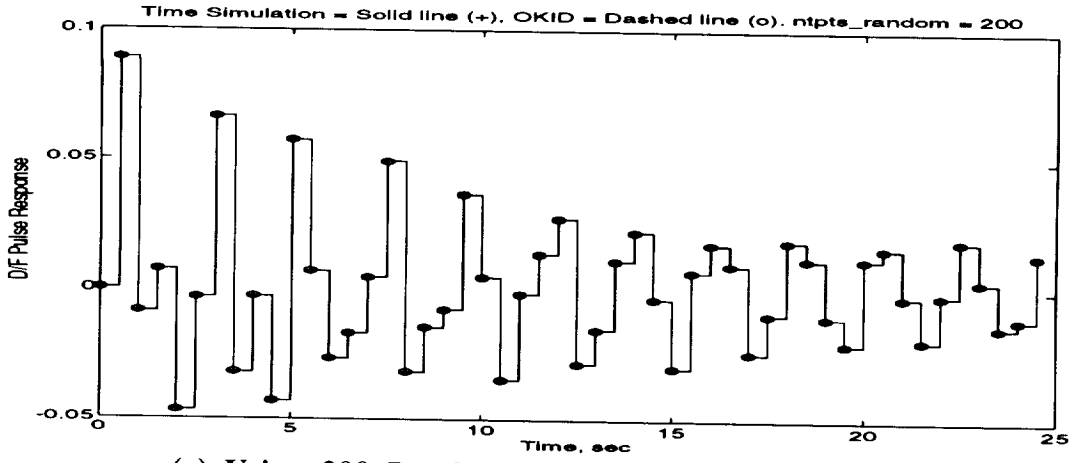
Fig. 2-18. Comparison of D/F PRFs: Time Simulation vs OKID With Initial Conditions



(a) Using 50 Random Input-Output Data Points



(b) Using 100 Random Input-Output Data Points



(c) Using 200 Random Input-Output Data Points

Fig. 2-19. Comparison of D/F PRFs: Time Simulation vs OKID Without Initial Conditions

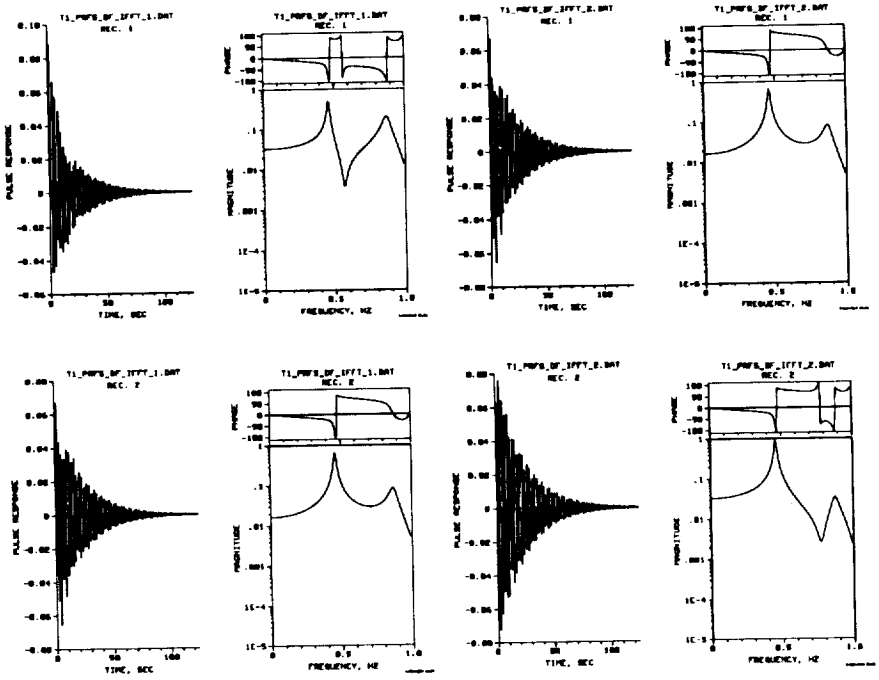


Fig. 2-20. D/F PRFs and FRFs: 2 Inputs (Cols), 2 Outputs (Rows)

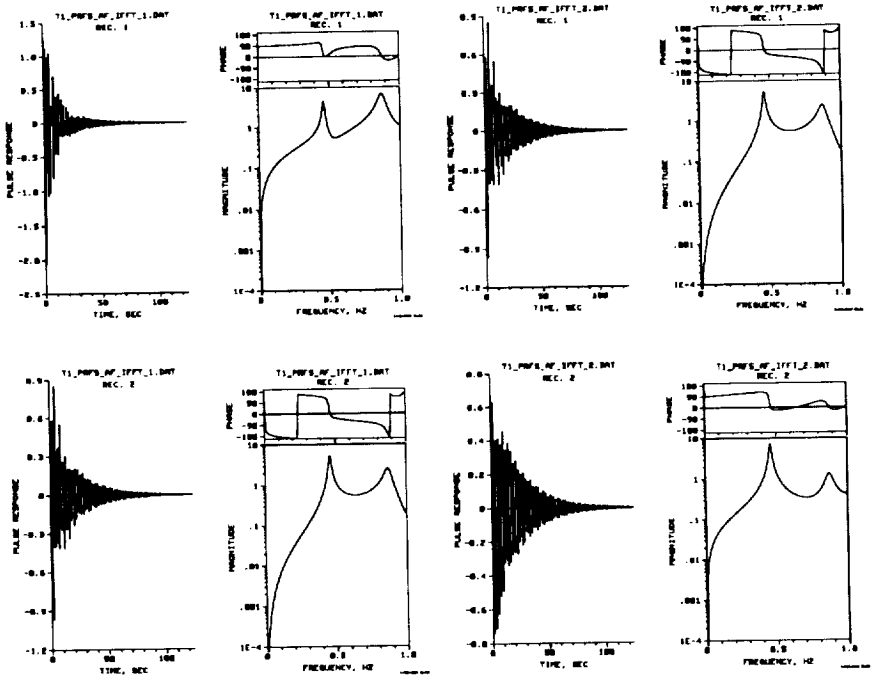


Fig. 2-21. A/F PRFs and FRFs: 2 Inputs (Cols), 2 Outputs (Rows)

Fig. 2-22 shows the singular values of $H_{rs}(1)$, $d_1 \geq d_2 \geq \cdots \geq d_M \geq 0$. The shaded bars represent those singular values retained in the analysis ($d_1 \geq d_2 \geq \cdots \geq d_n > 0$). Singular-value truncation is based on the numerical rank of $H_{rs}(1)$, selected by specifying software parameter NUMRNK = 1. This truncation method is appropriate when analyzing noise-free simulated data (ref. Chapter 6 and discussion of Tape50 output file in Section 3.6).

Exactly 4 nonzero singular values occur in each of the DLSIM analyses. In contrast to the approximate simulation of IRFs of a continuous-time system discussed in Section 2.3.2,[67] the simulation of PRFs of a discrete-time system is exact.[68] In each of the OKID analyses, on the other hand, there are 8 nonzero singular values. The 4 additional singular values are caused by residual observer dynamics of the OKID procedure. A large drop in amplitude of approximately 50 dB (a ratio of approx. 300) occurs after the 4th singular value with both the D/F and A/F data, however, indicating that a 4th-order model provides a good approximation. In both DLSIM analyses, ERA identifies exactly 2 structural modes. In both OKID analyses, ERA identifies 3 structural modes, 2 having very high accuracy indicators and the other having very low accuracy indicators. The 2 modes with high accuracy indicators are the true structural modes.

Table 2-5 compares the true values of the modal parameters (from Table 2-1) with the ERA identification results for all 4 cases. Note that mass-scaled mode shapes are unavailable because computer program ERAP11 assumes a continuous-time model representation (ref. Section 3.15). All modal parameters are identified exactly with DLSIM data. With OKID data, the maximum frequency error is 0.02%, the maximum damping-factor error is 1.5%, and the maximum mode shape error is 0.78%.

As mentioned in Section 2.4.1, modal parameters are typically not of interest when ERA is used to identify a discrete state-space model for control design. The end product of the analysis is the $[A,B,C,D]$ model, Eq. 2-39. Model accuracy is evaluated by comparing measured dynamic responses with corresponding model predictions.[69] In particular, predicted PRFs of the model are calculated as follows:

[67]The excitation impulse is approximated numerically by a trapezoid of unit area (the excitation sequence is interpolated using a first-order hold).

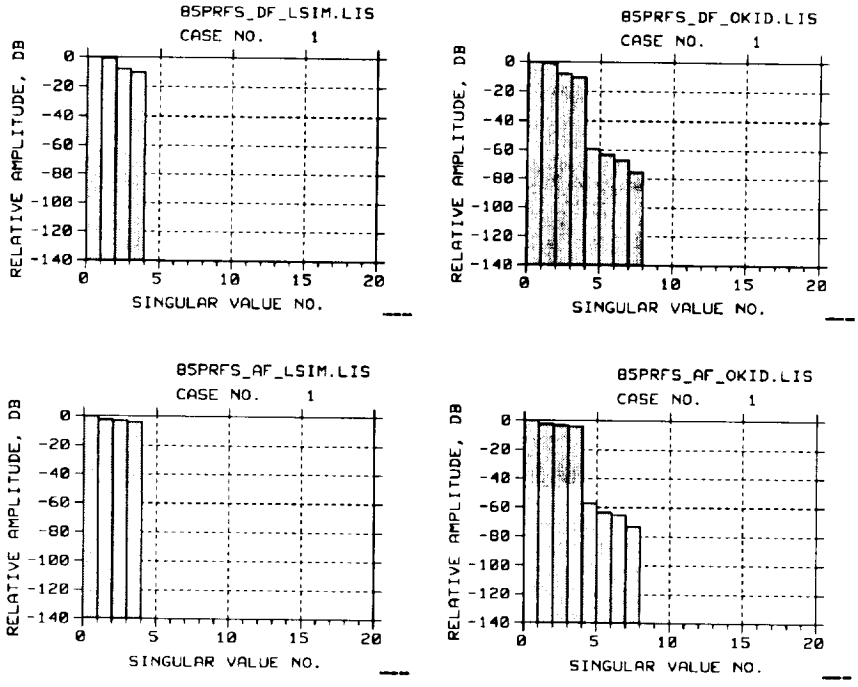
[68]Of course, this does not guarantee that actual experimental data match simulations exactly. Simulated PRFs of a discrete-time system calculated with the DLSIM MATLAB function exactly match the assumed theoretical equation, Eq. 2-37. With experimental data, however, other factors such as noise, nonlinearity, unmeasured disturbances, etc. always cause some degree of mismatch with Eq. 2-37. These distortions cause increased uncertainty in determining the number of "significant" singular values.

[69]This is a necessary but insufficient measure of accuracy for a structural-modal-parameter model.

$$\hat{Y}(k) = \begin{cases} D & for\ k = 0 \\ CA^{k-1}B & for\ k = 1,2,3,\cdots \end{cases}$$

using the identified $[A,B,C,D]$ matrices. These predictions are compared with the measured PRFs, $Y(k)$, that were analyzed by ERA to obtain the model. **Figs. 2-23 and 2-24** show such comparisons of actual ("measured") h_{11} PRFs and PRFs predicted using the ERA-identified models from the DLSIM data analyses. The actual and predicted PRFs are essentially identical for both the D/F and A/F cases.[70]

[70]Predicted responses of discrete-time systems are computed using ERA post-processor program ERAP10B (ref. Section 3.16.2).

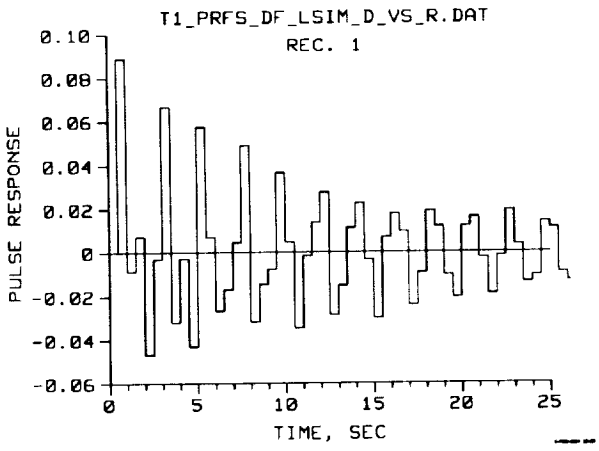


Upper Left: Using D/F DLSIM Data Upper Right: Using D/F OKID Data
Lower Left: Using A/F DLSIM Data Lower Right: Using A/F OKID Data

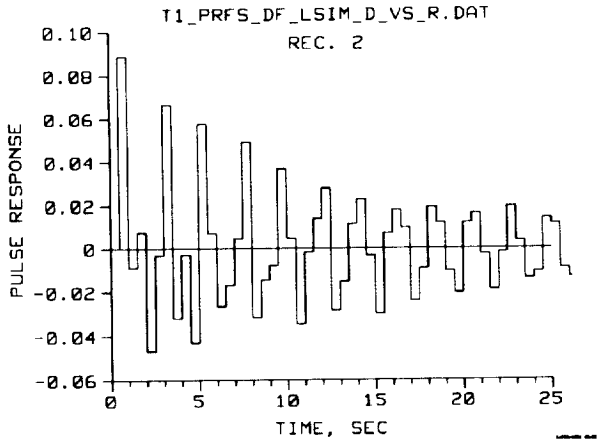
Fig. 2-22. Singular Values From ERA Analysis of PRFs

	True Values	D/F DLSIM	D/F OKID	A/F DLSIM	A/F OKID
f_d, Hz	0.4594 0.8714	0.4594 0.8714	0.4595 0.8714	0.4594 0.8714	0.4595 0.8714
ζ, %	1.443 2.739	1.443 2.739	1.428 2.780	1.443 2.739	1.428 2.780
Ampl.-Scaled Mode 1	75.00 100.00	75.00 100.00	75.01 100.00	75.00 100.00	75.02 100.00
Ampl.-Scaled Mode 2	100.00 -40.00	100.00 -40.00	100.00 -39.69	100.00 -40.00	100.00 -39.91
Mass-Scaled Mode 1	0.5371 0.7161	N/A	N/A	N/A	N/A
Mass-Scaled Mode 2	0.9806 -0.3922	N/A	N/A	N/A	N/A

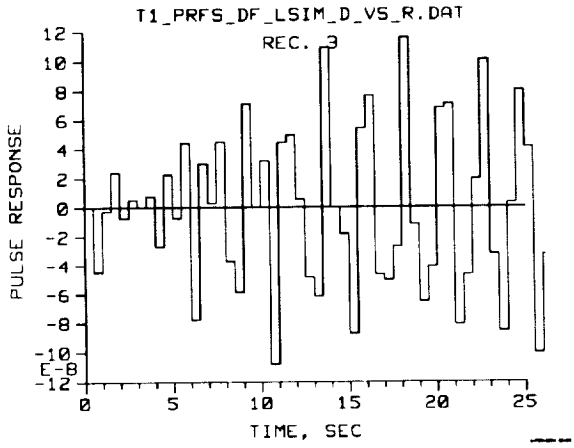
Table 2-5. ERA Results For MATLAB 2-DOF Problem Using Discrete-Time Model (PRFs)



(a) Actual $h_{d,11}$ PRF

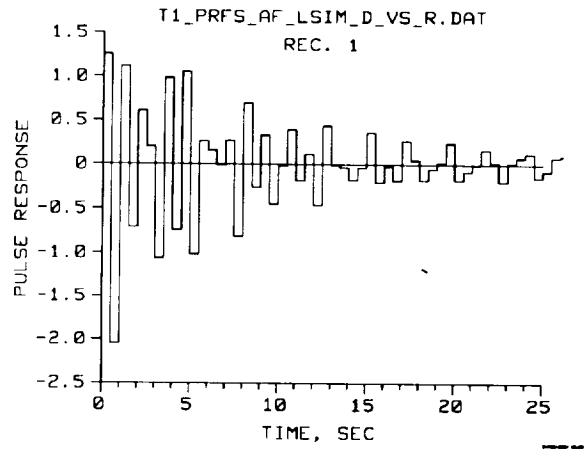


(b) Predicted $h_{d,11}$ PRF

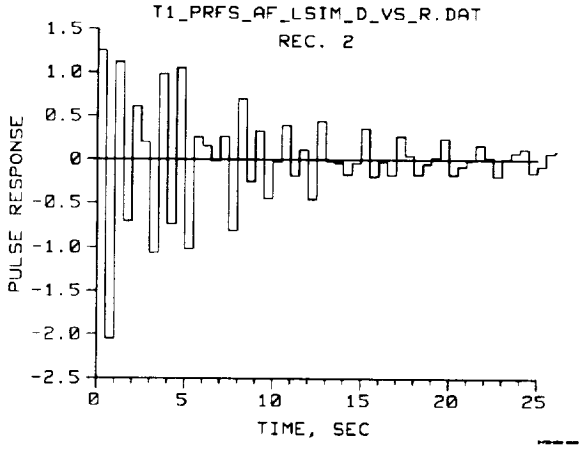


(c) Error: Fig. (a) - Fig. (b) (Note E-8 Scale Factor)

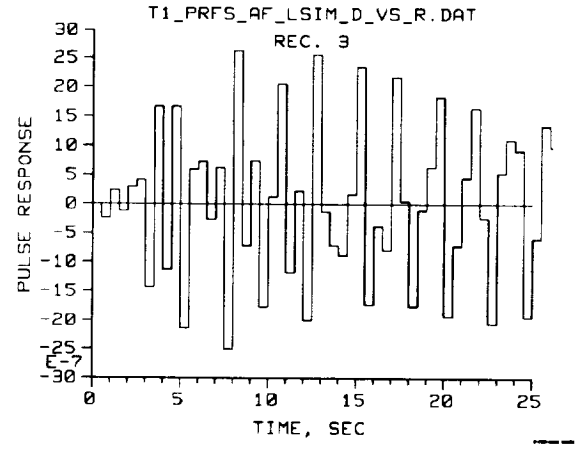
Fig. 2-23. D/F PRF vs Predicted PRF Using ERA-Identified Model



(a) Actual $h_{a,11}$ PRF



(b) Predicted $h_{a,11}$ PRF



(c) Error: Fig. (a) - Fig. (b) (Note E-7 Scale Factor)

Fig. 2-24. A/F PRF vs Predicted PRF Using ERA-Identified Model

2.5 Free Decay vs Impulse or Pulse Response Data

The sampled, free-decay response of a continuous-time system, Eq. 2-14, from arbitrary initial conditions is

$$\overline{Y}_c(k) = CA^k X(0) \qquad (p \times \overline{q}) \tag{2-46}$$

for $k = 0,1,2,\cdots$, where $A = e^{A_c \Delta t}$ is the state-transition matrix, and Δt is the data sampling interval. The ith column of $\overline{Y}_c(k)$ contains the free response of the system $(u(t) = 0, t \geq 0)$ to the ith set of nonzero initial conditions, $x(0)$, stored in the ith column of $X(0)$. A total of $\overline{q}$ separate initial conditions are considered.

Similarly, the free-decay response of a discrete-time system, Eq. 2-36, from arbitrary initial conditions is also

$$\overline{Y}_d(k) = CA^k X(0) \qquad (p \times \overline{q}) \tag{2-47}$$

for $k = 0,1,2,\cdots$. The ith column of $\overline{Y}_d(k)$ contains the free response of the system $(u(k) = 0, k \geq 0)$ to the ith set of nonzero initial conditions, $x(0)$, stored in the ith column of $X(0)$. A total of $\overline{q}$ separate initial conditions are again considered.

Clearly, Eqs. 2-46 and 2-47 are identical to Eq. 2-16 $(Y(k) = CA^k B)$ with $X(0)$ playing the role of B. Therefore, the ERA solution for a continuous-time system presented in Section 2.3.1 is also applicable to free-decay responses. The solution (Eq. 2-31) generates $[A, X(0), C]$ rather than $[A, B, C]$. Valid natural frequencies, damping factors, and mode shapes are obtained after transformation to modal coordinates (Eq. 2-32).[71] However, modal masses (mass-scaled mode shapes) are unavailable.

2.6 Accuracy Indicators

In practice, some modal parameters obtained by the approach described in the previous sections are inaccurate due to measurement noise, nonlinearity, unmeasured disturbances, etc. Various "accuracy indicators" have been developed to assess the relative accuracy of the results. This section describes these indicators.

[71] Section 2.6.3.2 describes a procedure for rotating the mode shapes to align best with ± 90°.

2.6.1 Consistent-Mode Indicator (CMI)

The Consistent-Mode Indicator (CMI) is the primary ERA accuracy indicator. A single value ranging from 0-100% is obtained for each identified mode. Furthermore, the results can be decomposed into constituent components associated with each input (initial condition) and output (response measurement) or input-output pair.[72] Both temporal and spatial consistency calculations are included in the formulation. Modes with CMI values greater than approximately 80% are identified with high confidence. Modes with values ranging from 80-1% display moderate to large uncertainty. Fictitious "computational modes" have CMI values of approximately zero.

CMI is computed for mode i as the product of two other parameters, EMAC and MPC:

$$CMI_i = EMAC_i \cdot MPC_i \quad (x\,100\%)\,. \tag{2-48}$$

Extended Modal Amplitude Coherence (EMAC) quantifies the temporal consistency of the identification results. Modal Phase Collinearity (MPC) quantifies the spatial consistency of the identification results. Practical experience has shown that both conditions must be satisfied simultaneously to ensure accurate results (Ref. 6). These two parameters are described separately in the following sections.

2.6.2 Extended Modal Amplitude Coherence (EMAC)

In the original formulation of ERA (Ref. 3), a parameter known as the Modal Amplitude Coherence (γ) was introduced. **EMAC is a much-improved version of this formulation**. Under certain common conditions, γ values can be high (even 100 percent) for all eigenvalues. This insensitivity is avoided with EMAC. The term "extended" in the new name refers to the extension of the primary data analysis window for the final block row and block column of the generalized Hankel matrices. EMAC quantifies the temporal consistency of the identified modal parameters by measuring the predictability of the results in this extended time interval. This test is much more difficult to fulfill than testing only the predictability of the results in the primary analysis window, which is what γ does. EMAC also involves many fewer calculations than γ. Overall, it provides a more-sensitive, more-reliable approach than γ with proven usefulness based on many successful applications (e.g., Refs. 6 and 8).

EMAC is computed using the identified modal parameters. Mode shape and modal participation components for data at $t = 0$ are compared with corresponding components

[72]Constituent components are printed on the "Tape55" output file. Details available in Sections 3.14 and 5.3.

for data at $t = T_O$ (for outputs) or $t = T_I$ (for inputs) located in the final block row and final block column, respectively, of the modal observability matrix (MOM):

$$\overline{V} = PD^{1/2}\Psi \tag{2-49}$$

and modal controllability matrix (MCM):

$$\overline{W} = \Psi^{-1}D^{1/2}Q^T . \tag{2-50}$$

Data in the corresponding final block row (block row r) and final block column (block column s) of the generalized Hankel matrices, Eq. 2-17, are shifted by 10 time samples (by default) from the previous block row and block column, providing an extension of the primary data analysis window.[73] An EMAC value is computed for each of the p outputs (response measurements) and q inputs (initial conditions), for every mode.

Let $\left(\phi_{ij}\right)_0$ be the identified mode shape component of mode i and response measurement j at $t = 0$ and $\left(\phi_{ij}\right)_{T_O}$ be the corresponding identified component at $t = T_O$. The identified eigenvalue of mode i is s_i. Compute a predicted value of $\left(\phi_{ij}\right)_{T_O}$ as follows:

$$(\tilde{\phi}_{ij})_{T_O} = \left(\phi_{ij}\right)_0 \cdot e^{s_i T_O} . \tag{2-51}$$

Temporal consistency is quantified by comparing $\left(\phi_{ij}\right)_{T_O}$ and $(\tilde{\phi}_{ij})_{T_O}$. The actual and predicted magnitudes are compared using the ratio of the magnitudes:

$$\begin{aligned} R_{ij} &= \left|(\phi_{ij})_{T_O}\right| / \left|(\tilde{\phi}_{ij})_{T_O}\right| \quad \text{for} \quad \left|(\phi_{ij})_{T_O}\right| \le \left|(\tilde{\phi}_{ij})_{T_O}\right| \\ &= \left|(\tilde{\phi}_{ij})_{T_O}\right| / \left|(\phi_{ij})_{T_O}\right| \quad \text{otherwise} . \end{aligned} \tag{2-52}$$

The actual and predicted phase angles are also compared. Letting

[73] Block rows 2 through $r-1$ and block columns 2 through $s-1$ of the Hankel matrices are shifted by 1 time sample (by default) from the previous block row and column, and block row r and block column s are shifted by 10 time samples (by default) from the previous block row and column. In software terminology, block rows 2 through $r-1$ and block columns 2 through $s-1$ are shifted by N2 and N3 time samples, respectively. Block row r and block column s are shifted by N2LAST and N3LAST time samples, respectively. The default value of N2 and N3 is 1. The default value of N2LAST and N3LAST is 10. Appendix K and Chapter 6 contain additional information.

$$P_{ij} = Arg\left[\frac{(\phi_{ij})_{T_o}}{(\tilde{\phi}_{ij})_{T_o}}\right], \quad -\pi \le P_{ij} \le \pi \tag{2-53}$$

a weighting factor is determined as follows:[74]

$$W_{ij} = 1.0 - \left[\frac{|P_{ij}|}{\pi/4}\right] \quad \text{for} \quad |P_{ij}| \le \pi/4$$
$$= 0.0 \quad \text{otherwise}. \tag{2-54}$$

An Output EMAC for mode i and response measurement j is then computed as:

$$EMAC_{ij}^{\ O} = R_{ij} \cdot W_{ij} \quad (x\,100\%). \tag{2-55}$$

An Input EMAC for mode i and initial condition k, $EMAC_{ik}^{\ I}$, is similarly computed using the identified modal participation factors, the identified eigenvalue s_i, and T_I.

Using these results, an EMAC value is associated with every j-k'th input-output pair as follows:

$$EMAC_{ijk} = EMAC_{ij}^{\ O} \cdot EMAC_{ik}^{\ I} \quad (x\,100\%). \tag{2-56}$$

Finally, to condense all EMAC results for mode i into a single value, a weighted average of the individual results is computed:

$$EMAC_i = \frac{\sum_{j=1}^{p}\sum_{k=1}^{q} EMAC_{ijk} \cdot |\phi_{ij}|^2 \cdot |\phi_{ik}|^2}{\sum_{j=1}^{p}\sum_{k=1}^{q} |\phi_{ij}|^2 \cdot |\phi_{ik}|^2}$$
$$= \frac{(\sum_{j=1}^{p} EMAC_{ij}^{\ O} \cdot |\phi_{ij}|^2)(\sum_{k=1}^{q} EMAC_{ik}^{\ I} \cdot |\phi_{ik}|^2)}{\sum_{j=1}^{p} |\phi_{ij}|^2 \cdot \sum_{k=1}^{q} |\phi_{ik}|^2} \tag{2-57}$$

[74] $\pi/4$ in Eq. 2-54 is an empirical value based on modal identification results for several experimental and simulated data sets.

where ϕ_{ij} and ϕ_{ik} are mode shape and modal participation components, respectively. A weighting factor of $|\phi|^2$ is used to achieve an energy-type emphasis.

2.6.3 Modal Phase Collinearity (MPC)

MPC quantifies the spatial consistency of the identification results. For classical normal modes, all locations on the structure vibrate exactly in-phase or out-of-phase with one another; i.e., the corresponding mode shape is a real or "monophase" vector.

With monophase behavior, the 2 x 2 variance-covariance matrix of the real and imaginary parts of the mode shape vectors has only one nonzero eigenvalue. If the identified mode shape phase angles are uncorrelated, on the other hand, the two eigenvalues of this matrix are approximately equal. MPC quantifies the degree of monophase behavior by comparing the relative size of the eigenvalues of the variance-covariance matrix.

Let Φ_i' and Φ_i'' be the real and imaginary parts, respectively, of the identified mode shape of mode i. Calculate the variance and covariance of the real and imaginary parts:

$$\begin{aligned} S_{xx} &= \Phi_i'^T \Phi_i' \\ S_{yy} &= \Phi_i''^T \Phi_i'' \\ S_{xy} &= \Phi_i'^T \Phi_i''. \end{aligned} \tag{2-58}$$

Letting

$$\eta = \frac{S_{yy} - S_{xx}}{2S_{xy}} \tag{2-59}$$

the eigenvalues of the variance-covariance matrix are

$$\lambda_{1,2} = \frac{S_{xx} + S_{yy}}{2} \pm S_{xy}\sqrt{\eta^2 + 1}\,. \tag{2-60}$$

MPC for mode i is then defined as follows:

$$MPC_i = \left(\frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2}\right)^2 \quad (x\,100\%)\,. \tag{2-61}$$

MPC_i values range from 0.0 for a mode with completely uncorrelated phase angles to 100% for a monophase result.

This formulation of MPC is based on the original definition in Ref. 3 of Modal Phase Collinearity (μ) except normalized to generate values ranging from 0 to 100%. The smallest

possible value of μ was inadvertently limited to 25%. Also, two practical extensions of the MPC concept are presented in the following two subsections.

2.6.3.1 Unweighted MPC

The definition of MPC in Eqs. 2-58 through 2-61 provides a natural weighting based on the magnitude of the individual mode shape components. This weighting is desirable because phase angle results for small experimentally determined mode shape components are often inaccurate due to measurement limitations. However, it is also useful to repeat the calculations without this natural weighting imposed; i.e., by normalizing each mode shape component to unit magnitude before calculating the variance and covariance values. For global modes, this "unweighted MPC" will be approximately equal to the standard "weighted MPC" defined above. For local modes, however, the unweighted value will be considerably smaller than the weighted value. The magnitude of the difference provides a quick and effective indicator of global versus local response behavior.[75]

2.6.3.2 Phase Rotation For Free-Decay Data

When ERA is applied to displacement/force or acceleration/force impulse response functions, the identified mode shapes have large imaginary parts and small real parts. With free-decay data for arbitrary initial conditions, however, the identified mode shapes have arbitrary mean phase angle.[76] Before these (complex) mode shapes can be plotted as deformation patterns or used in certain other calculations such as the Phase Resonance Criterion (Ref. 11), they must be rotated to align best with ± 90°. The necessary rotation angle α is

$$\alpha = \tau + \pi/2 \tag{2-62}$$

where

$$\tau = \tan^{-1}\left(\eta + sgn(S_{xy})\sqrt{\eta^2 + 1}\right). \tag{2-63}$$

2.6.4 Modal Strength Ratio (MSR)

MSR for mode i is the root-mean-square (rms) identified amplitude of mode i divided by the total rms amplitude of all data samples included in the generalized Hankel matrix, $H_{rs}(0)$, Eq. 2-17.

[75] A global mode is a mode having significant motion at most measurement locations. A local mode has significant motion at only a few measurement locations. Weighted and unweighted MPCs are printed on the Tape50 output file under the headings of "MPC-W" and "MPC-U," respectively.

[76] Phase angle = $\tan^{-1}$(Imaginary part / Real part).

By Eqs. 2-25, 2-49, and 2-50, $H_{rs}(0)$ can be decomposed into the sum of contributions of the m identified modes as follows:

$$H_{rs}(0) = \overline{V}\,\overline{W} = H'_{rs,1}(0) + H''_{rs,1}(0) + H'_{rs,2}(0) + H''_{rs,2}(0) + \cdots + H'_{rs,m}(0) + H''_{rs,m}(0) \quad (2\text{-}64)$$

where

$$H'_{rs,i}(0) = PD^{1/2}\psi'_i \cdot \varphi_i'^{\,T} D^{1/2} Q^T \quad (2\text{-}65)$$

contains the real amplitude components of mode i and

$$H''_{rs,i}(0) = PD^{1/2}\psi''_i \cdot \varphi_i''^{\,T} D^{1/2} Q^T \quad (2\text{-}66)$$

contains the corresponding imaginary amplitude components. Vector ψ'_i is the real part of the right eigenvector of A for mode i (a column of matrix Ψ), and vector $\varphi_i'^{\,T}$ is the real part of the left eigenvector of A for mode i (a row of matrix Ψ^{-1}). Vectors ψ''_i and $\varphi_i''^{\,T}$ are corresponding imaginary parts.

Calculate the rms identified amplitude of mode i as

$$rms_i = \sqrt{X'_i + X''_i} \quad (2\text{-}67)$$

where X'_i is the mean-square value of all elements of matrix $H'_{rs,i}(0)$ and X''_i is the mean-square value of all elements of matrix $H''_{rs,i}(0)$.

The MSR for mode i is

$$MSR_i = \frac{rms_i}{rms_T}. \quad (2\text{-}68)$$

where rms_T is the total rms amplitude of all elements of matrix $H_{rs}(0)$.

MSR measures the relative strength of each identified mode. Strongly excited modes have MSR values greater than approximately 10%, and weakly excited modes have MSR values less than approximately 1%.[77] In general, ERA identifies strongly excited modes more accurately than weakly excited modes.[78]

[77] A low MSR value usually means that the mode is weakly excited. However, it is also possible that the mode is strongly excited but only weakly observed due to inadequate measurement locations.

[78] With nonlinearities, however, strongly excited modes may be identified less accurately (in terms of linear, modal characteristics) than weakly excited ones. Nonlinearities are common in practice.

The square root of the sum of the squares of all MSR values should be approximately 100%. Values between 90% and 110% are typically obtained in practice, however, due to identification of real eigenvalues (not included in the MSR calculation) and less than perfect orthogonality between modal amplitudes, particularly with short data records. You can print the square root of the sum of the squares of the MSR values onto the Tape50 output file by specifying analysis parameter MSRTOT = 1 (1=on, 0=off). By default, MSRTOT = 0. MSRTOT is an acronym for "MSR Total."

Note: Fictitious "computational modes" may have relatively high MSR values (e.g., as high as 20% or more), so care must be exercised in interpreting these results. Computational modes are usually distinguishable from valid, structural modes by low CMI values (ref. Section 2.6.1).

2.6.5 Reciprocity

A reciprocity check is an excellent accuracy indicator when impulse response or pulse response data are used in the analysis. (The results are meaningless with arbitrary free-decay data). Reciprocity for mode i is the square of the correlation coefficient between the vector of identified modal participation factors at each available driving point and the vector of identified mode shapes at the same set of points, defined as follows:[79]

$$\rho_i = \frac{\left|\chi_i{}^H \phi_i\right|^2}{\left(\chi_i{}^H \chi_i\right)\left(\phi_i{}^H \phi_i\right)} \quad (x\,100\%) \tag{2-69}$$

where

χ_i = Vector of identified modal participation factors of mode i at the available driving points
ϕ_i = Vector of identified mode shapes of mode i at the available driving points
H = Hermitian transpose.

Perfect reciprocity corresponds to a ρ value of 100%. Good reciprocity corresponds to ρ values greater than approximately 90%. Poor reciprocity corresponds to ρ values less than approximately 50%.

Calculation of a valid correlation coefficient requires at least 2 data points in each vector; i.e., at least 2 driving-point IRFs or PRFs must be included simultaneously in the ERA analysis. If only 1 driving-point function is available, the reciprocity calculation is meaningless (designated by -999.0 on the Tape50 output file).

[79]Driving-point IRFs and PRFs have collocated input and output.

2.6.6 ZETA2

"ZETA2" (ζ_2) is a second damping factor estimate. Calculation of ZETA2 for mode i uses the identified mode shape components corresponding to data in $H_{rs}(0)$, Eq. 2-17, located at the beginning and end of the analysis time window and the corresponding identified damped natural frequency, as follows:

$$\zeta_{2,i} = -\frac{\sigma_{2,i}}{\omega_{n2,i}} \quad (x\,100\%) \tag{2-70}$$

where

$$\sigma_{2,i} = \frac{\ln\left(A_{e,i}/A_{b,i}\right)}{T} \tag{2-71}$$

$$\omega_{n2,i} = \sqrt{\sigma_{2,i}^{\,2} + \omega_{d,i}^{\,2}} \tag{2-72}$$

$A_{b,i}$ = Maximum identified mode-shape component of mode i at the beginning of the analysis window
$A_{e,i}$ = Corresponding identified mode-shape component of mode i at the end of the analysis window
T = Duration of analysis window (sec)
$\omega_{d,i}$ = Identified damped natural frequency of mode i (rad/sec).

Ideally, ζ_2 equals the damping factor, ζ, calculated from the identified s-plane eigenvalue, Eq. 2-34. In practice, however, differences occur. The magnitude of the difference is a reliable indicator of damping uncertainty. By default, ERA reports the ζ damping value. The relative accuracy of ζ vs ζ_2 is not yet established.

2.6.7 ARATIO

"ARATIO" (α) is an abbreviation for "Amplitude Ratio." ARATIO for mode i is

$$\alpha_i = \frac{A_{e,i}}{A_{b,i}} \tag{2-73}$$

where $A_{b,i}$ and $A_{e,i}$ are defined above (Section 2.6.6).

ARATIO helps estimate the suitability of the data-analysis window length (NTIM data samples). A small ARATIO value (e.g., less than 0.05) indicates that the data near the end of the analysis window is probably affected significantly by noise, particularly if the Modal

Strength Ratio (Section 2.6.4) is small (e.g., less than 1.0). Under these conditions, the identification accuracy of this mode would probably improve using a shorter window length. With a large ARATIO value (e.g., greater than 0.50), on the other hand, the identification accuracy of this mode would probably improve using a longer window length.

2.6.8 Reconstruction

Predicted responses of an ERA-identified model (consisting of either modal parameters or [A,B,C,D]) are often compared with corresponding measurements. Good agreement of predicted and measured responses is a necessary, **but not sufficient**, condition of accurate structural modal identification.[80] The process of computing response functions such as IRFs or FRFs is called "reconstruction" because the functions are "reconstructed" from individual modal components. Responses due to other, general, input time histories may also be predicted using an ERA-identified model, and this process is also sometimes called "reconstruction" or simply "response prediction."

In structural modal-identification applications, reconstructed FRFs are often compared with corresponding experimental FRFs. Additional comparisons are also made of reconstructed FRFs with individual modes or groups of modes in order to examine individual contributions. **Figs. 2-25 and 2-26** compare IRFs and FRFs for the MATLAB 2-DOF problem with a continuous-time model representation. Fig. 2-25 compares the overall reconstructed IRF and FRF (bottom plots) with the corresponding "measurement" (upper plots). Fig. 2-26 shows each ERA-identified mode separately. There is excellent agreement of the data and reconstructed function.[81]

Figs. 2-27 and 2-28 show corresponding results for PRF and FRF data with a discrete-time model representation. There is also excellent agreement of data and reconstruction here.[82]

---

[80]When [A,B,C,D] is used for control design (modal parameters are not of interest), good agreement of predicted and measured responses may be a sufficient condition as well. Modal-parameter inaccuracy may not affect control design as long as input-output behavior is predicted closely.

[81]The following "GO Input files" (ref. Chapter 8) generate these results: P10_IRFS_DF_IFFT.COM, P88_1_IRFS_DF_IFFT.COM, P88_2_IRFS_DF_IFFT.COM, G1B_P10_IRFS_DF_IFFT.COM, and G1F_P10_IRFS_DF_IFFT.COM.

[82]The following "GO Input files" (ref. Chapter 8) generate these results: P10B_1_PRFS_DF_IFFT.COM, P10B_2_PRFS_DF_IFFT.COM, P88_1_PRFS_DF_IFFT.COM, P88_2_PRFS_DF_IFFT.COM, G1B_P10B_PRFS_DF_IFFT.COM, and G1F_P10B_PRFS_DF_IFFT.COM.

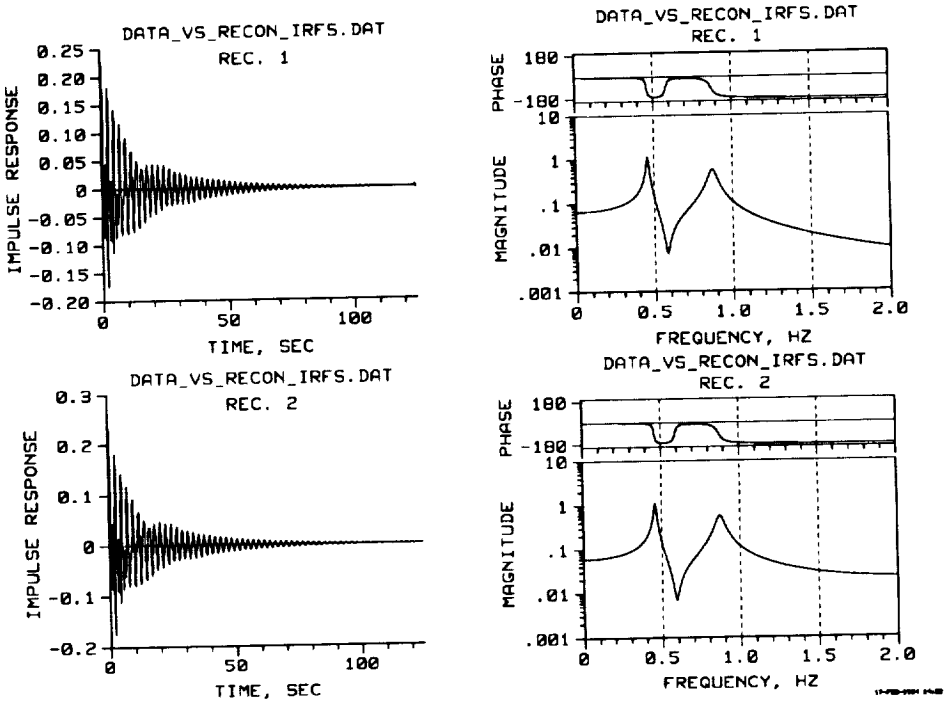


Fig. 2-25. Comparison of Data (Top) With Continuous-Time Reconstruction (Bottom)

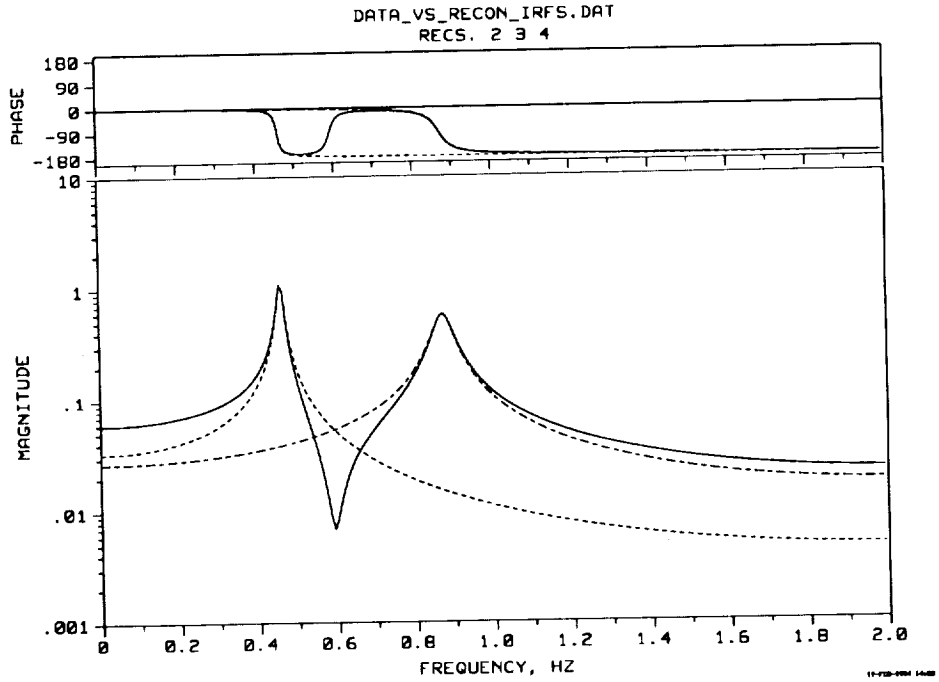


Fig. 2-26. Comparison of Continuous-Time Reconstructed Spectrum (Solid Line) With Individual Modal Components (Dashed Lines)

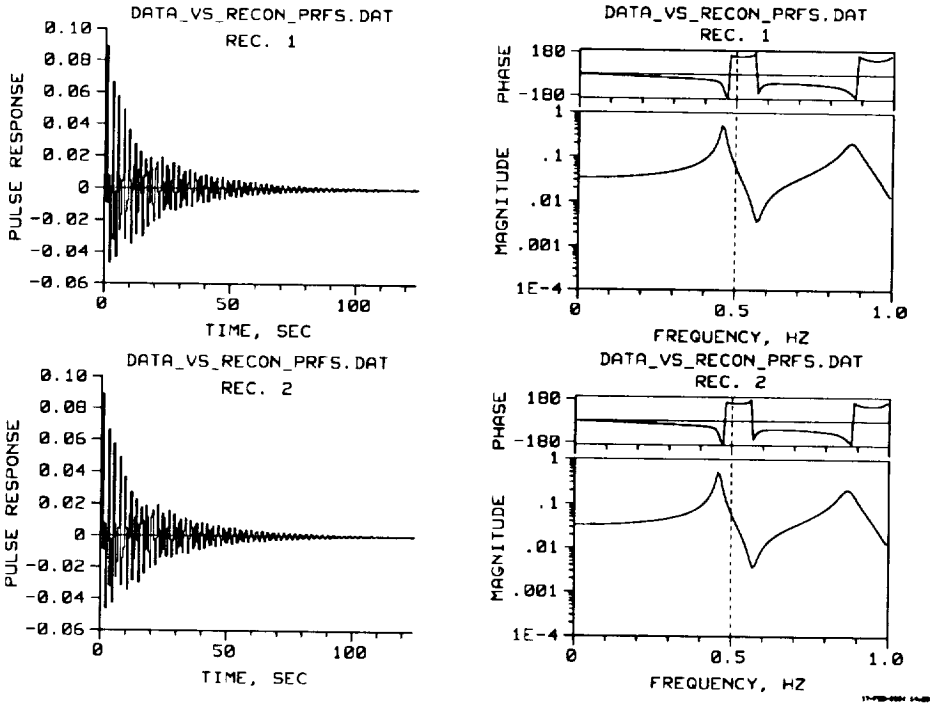


Fig. 2-27. Comparison of Data (Top) With Discrete-Time Reconstruction (Bottom)

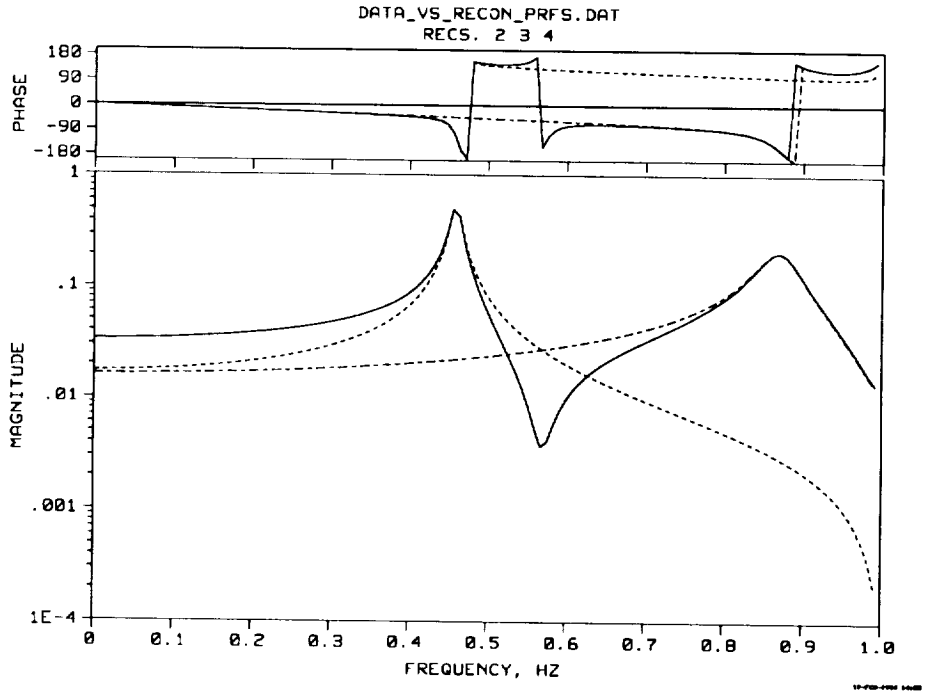


Fig. 2-28. Comparison of Discrete-Time Reconstructed Spectrum (Solid Line) With Individual Modal Components (Dashed Lines)

3.0 DEMONSTRATION PROBLEM

This chapter demonstrates principal software features for new users. It covers 16 steps comprising a structural modal-identification application using frequency response functions.[83] The procedural files used in the demonstration can be copied and edited for other applications. Simulated, low-noise data are analyzed so that the identified modal parameters can be compared with their true, known values.

The "test article" for this demonstration problem is the 20-meter-long Mini-Mast truss discussed in Refs. 6 and 7. Data for ERA consists of 312 impulse response functions (3 shaker locations and 104 response measurements) obtained by inverse Fourier transformation of displacement/force frequency response functions (FRFs). The FRFs are calculated using NASTRAN-predicted natural frequencies and mode shapes as follows:[84]

$$H_{kl}(\omega) = \sum_{r=1}^{N} \frac{\psi_{kr}\psi_{lr} / m_r}{(\omega_{nr}{}^2 - \omega^2) + j2\zeta_r\omega_{nr}\omega} \tag{3-1}$$

where: $H_{kl}(\omega)$ = FRF between response measurement k (displacement) and shaker location l (force)

N = No. of modes

ψ_{kr} = Shape of mode r at response measurement k

ψ_{lr} = Shape of mode r at shaker location l

m_r = Mass of mode r

ω_{nr} = Undamped natural frequency[85] of mode r

ω = Frequency in rad/sec = $2\pi f$

f = Frequency in Hz

ζ_r = Viscous damping factor (fraction of critical damping) of mode r

j = $\sqrt{-1}$

The calculation includes all 153 NASTRAN-predicted modes below 100 Hz, with the 0 to 80 Hz bandwidth then extracted for analysis. Modes 1 and 2 have a damping factor of 2 percent, mode 3 a damping factor of 1.5 percent, and modes 4 through 153 a damping factor of 1 percent. These damping selections are based on initial estimates of the

[83] Applications using free-decay data follow essentially the same steps. Section 2.5 discusses the differences.

[84] The objective of modal identification is to determine the parameters in Eq. 3-1 $(N, (f_{nr} = \frac{\omega_{nr}}{2\pi}, \zeta_r, \{\psi\}_r, m_r \text{ for } r = 1, N))$ from measurements of $H_{kl}(\omega)$. Eq. 3-1 is equivalent to Eq. 2-10.

[85] ERA identifies damped natural frequencies, $\omega_{dr} = \omega_{nr}\sqrt{1-\zeta_r{}^2}$.

experimental values. The simulated impulse-response functions are analyzed with ERA to identify structural modal parameters (natural frequencies, damping factors, mode shapes, and modal masses).

The following 16 steps are typically performed in structural modal-identification projects:

1. Data Acquisition.
2. Data Preview.
3. Digital Filtering.
4. Selecting ERA Analysis Parameters.
5. Running ERA.
6. Examining the Tape50 Output File.
7. Comparison of Identified Frequencies With Spectral Peaks.
8. MAC and/or Orthogonality Calculations.
9. Mode Shape Plotting and/or Animation.
10. Looping Option No. 1 (No. of Retained Singular Values).
11. Looping Option No. 2 (Sliding Time Window).
12. Examining Distribution of CMI Values.
13. Improvement of Results Using High Nos. of Assumed Modes.
14. Improvement of Results Using KEYDTA.
15. Modal Mass Calculation.
16. Reconstruction.

This demonstration problem illustrates each of these steps using the Mini-Mast simulated data. The results are discussed in Sections 3.1 through 3.16, respectively.

New users should duplicate the results shown in this chapter on their own computers. Identical tabular output will be obtained. The graphical output, however, may vary slightly depending on the particular graphics terminal or hard copy device used. *You are encouraged at any time to modify various parameters of interest to examine the effects on the results.* Such self-guided "side trips" can significantly improve your understanding of the software.

It is beyond the scope of this User's Guide to discuss the additional complications that may arise when dealing with actual experimental data. Reference 6 provides some information on this topic including a comparison of ERA results for Mini-Mast using both simulated and experimental data. Considerable additional work may be necessary when analyzing experimental data with significant nonlinearities, modal clusters, local modes, weakly excited modes, background disturbances, signal processing biases, etc. Such complications are not uncommon in practical applications.

3.1 Data Acquisition (ERAP2)

Fig. 3-1 shows the steps taken to generate simulated data for this demonstration problem. A detailed NASTRAN model of Mini-Mast was developed and its normal modes of vibration below 100 Hz computed (Ref. 7). The natural frequencies and mode shapes of these modes (153 in total) were written to a NASTRAN Output2 file. Using the I-DEAS Data Loader program from SDRC, these data were translated to "universal file" (.UNV) format (Ref. 9). This universal file was read into the SDRC Test Data Analysis (TDAS) software package (Ref. 9) which has as a standard feature the capability to synthesize frequency response functions (FRFs).[86] Using an assumed damping factor of 2 percent for modes 1 and 2, 1.5 percent for mode 3, and 1 percent for all other modes, FRFs between 3 shaker locations (force) and 104 response measurements (displacement) were generated.

These FRFs were converted to impulse response functions (IRFs) for ERA analysis using program ERAP2.[87] IRFs are obtained by inverse Fourier transformation of FRFs. A low level of noise (0.1%) was then added to the IRFs using program ERAP99. **The resulting IRFs with noise are representative of good-quality experimental data.**

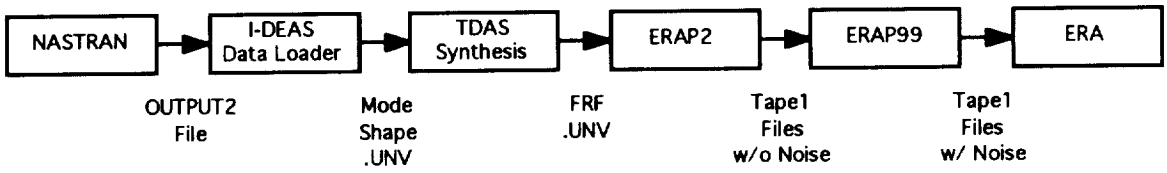


Fig. 3-1. Generation of Simulated Data for ERA

The FRF calculation includes all 153 modes up to 100 Hz. The 0 to 80 Hz bandwidth is then extracted for conversion to IRFs. **This procedure provides realistic simulation of experimental bandlimited FRFs which normally contain response contributions from nearby modes outside of the analysis bandwidth.**[88] There are 140 modes between 0 and 80 Hz, 108 of which appear in a cluster between 15 and 20 Hz. These 108 "local modes" are due to the bending of individual truss members (Refs. 6,7).

[86]Simulated FRFs can also be generated from NASTRAN mode-shape .UNV files using the recently developed utility program named ERAP30. ERAP30 is one of several ERA pre- and post-processors (ref. Chapter 8).

[87]Program ERAP2 is demonstrated later in Section 3.1.

[88]This topic is discussed further in Section 3.4 (ref. Fig. 3-4).

When ERA is applied to experimental data, other methods are used to generate FRFs (or free-decay data). Experimental data, however, are also often written in universal file format. When they are, the file format is identical to that obtained from TDAS as shown in Fig. 3-1. Thus, program ERAP2 is also used with experimental data sets.[89] The input data files for ERA created by ERAP2 are referred to as "Tape1 files." This terminology is a carry-over from use on CDC computers where the default file name for FORTRAN logical unit n is TAPEn. Section 4.1 describes the format of ERA Tape1 files.[90]

In the remainder of this section, you are given the opportunity to run program ERAP2 for this demonstration problem. Before beginning, however, the ERA software must be initialized. If you have not already done so, initialize the software as described in Section 1.5.

It is a good idea to create a new directory for your work. The suggested name for this directory is DEMO, which can be created under an existing directory (typically your login directory) using the VMS command:

```
CREATE/DIRECTORY [.DEMO]
```

Move into this directory by entering:

```
SET DEFAULT [.DEMO]
```

All ERA pre- and post-processors can be run by simply typing their name, e.g. ERAP2. **Rather than running pre- and post-processors interactively, however, a much quicker method is available.** This method is referred to as the "GO Method," named for the simple command used to initiate it. This approach is used to run ERAP2 now.

The global directory named ERA$GO contains sample GO input files. ERA$GO is a VMS logical name for directory ERA$DISK:[ERA.GO]. Copy the file named P2_DEMO.COM into your current default directory ([.DEMO]) by entering:

```
COPY ERA$GO:P2_DEMO.COM []

(or COPY ERA$GO:P2_DEMO.COM *)
```

Here is a listing of file P2_DEMO.COM:

---

[89] A pre-processor named ERAP1 written by a co-op student converts TDAS binary ADF files directly to ERA Tape1 format. However, potential bugs in this software have been reported which have not yet been diagnosed. The author uses program ERAP2 in applications with FRFs.

[90] You do not need to understand the format of Tape1 files to complete Chapter 3.

```
$! P2_DEMO.COM
$!
$ RUN ERA$EXES:ERAP2
ERA$MMST_NAS:T1_MMST_NAS_SH1_NONOISE_NST5.UNV  UNV FILE NAME
0         DOES ALL DATA IN THE FILE HAVE SAME REFERENCE?  1=YES
201       REF. LOCATION NO.
3         REF. DIRECTION
1         IS DATA FOR THIS REF. STORED CONTINUOUSLY IN THE FILE? 1=YES
1         LOWEST  RESPONSE LOCATION NO. TO PROCESS
100000    HIGHEST RESPONSE LOCATION NO. TO PROCESS (ENTER LARGE NO. FOR ALL)
1         SEQUENCE NO. TO READ IN  (-1 FOR ALL)
T1DEMO_NST5   TAPE1 FILENAME TO CONSTRUCT  (T1xxx)
1         SAVE COORDINATE CODES?  1=YES
          COORDINATE-CODE FILENAME      (DEFAULT = TCxxx)
2         FRFS GENERATED IN MODAL-PLUS [1] OR TDAS [2]?
1         FIRST RECORD TO PROCESS
100000    LAST RECORD TO PROCESS (ENTER LARGE NO. TO PROCESS ENTIRE FILE)
100000    NTIM [NO. OF TIME POINTS]  (ENTER LARGE NO. FOR ALL)
0         USE ONLY IMAG. PART OF H(W) TO COMPUTE h(t) ?  1=YES
```

This file is a standard VMS command procedure (".COM file") that executes program ERAP2 (line 3), followed by the responses to 16 questions asked by ERAP2. In addition to the responses, each line also contains a brief description of the corresponding question. Once you become familiar with a particular pre- or post-processor, these descriptions will be self-explanatory.

Although P2_DEMO.COM is a standard VAX/VMS .COM file, do not execute it in the usual manner using the "@" command. Using "@" alone is insufficient for some ERA pre- and post-processors, particularly those involving graphics. **Instead, run all GO input files by simply typing "GO" followed by the file name.** It is not necessary to type the ".COM" portion of the file name because this is the default file type for GO input files. **The GO input file is assumed to reside in your current default directory.** GO input files for program ERAxx are normally given names beginning with "xx_", although any name is permitted. For example, GO input files for ERAP2 written by the author have names beginning with "P2_".

Execute P2_DEMO.COM by entering:

```
GO P2_DEMO
```

The ERAP2 program runs very rapidly with questions and responses flashing to your computer screen at a rate too fast to read. This is normal. To examine this information more closely, you must pause the display using the standard Ctrl S/Ctrl Q commands (Ctrl S to stop and Ctrl Q to continue) or using the F1 key on DEC terminals. Another method for examining the questions asked by any pre- or post-processor is to redirect the terminal text to a disk file. This is accomplished conveniently by appending an additional file name with the GO command, for example:

```
GO P2_DEMO P2.OUT
```

Everything that normally appears on your computer screen is now redirected to file P2.OUT instead.

After all 16 questions and responses for ERAP2 scroll by, the listing slows down as computations are performed. Approximately 5 seconds are necessary on the author's VAXstation 3100 computer to calculate 5 data records. An end-of-file is encountered and the program stops.

Although the remainder of this demonstration problem uses 312 data records (IRFs), only the first 5 records are converted to ERA Tape1 format in this example. The input universal file specified in P2_DEMO.COM (file T1_MMST_NAS_SH1_NONOISE_NST5.UNV) contains only 5 records to conserve disk space. The entire 312-record Universal file is approximately 40,000 blocks (20 Mbytes) in size and is not provided. The objective of this section is to demonstrate the use of program ERAP2, not to actually construct the ERA input files used in the remainder of the chapter.

The following information appears on your computer screen when file P2_DEMO.COM is run:

```
ERAP2.  BUILDS A STD. ERA TAPE1 FILE FROM FRF DATA
        IN UNIVERSAL FILE FORMAT (TYPE 58)

ENTER FILE NAME CONTAINING UNV DATA. [DEFAULT FILE TYPE = .UNV]
ERA$MMST_NAS:T1_MMST_NAS_SH1_NONOISE_NST5.UNV

DOES ALL DATA IN THIS FILE HAVE THE SAME REFERENCE DOF ?  1=YES  (1)
          0

DATA FROM ONLY 1 REFERENCE WILL BE EXTRACTED.
* RUN ERAP2 AGAIN TO EXTRACT DATA FOR OTHER REFERENCES *

ENTER REFERENCE NODE NUMBER DESIRED ?  (1)
        201

ENTER REFERENCE DIRECTION DESIRED (1=X, -1=X-, ETC) ?  (1)
          3

IS ALL DATA FOR THIS REFERENCE STORED CONTIGUOUSLY
IN THE .UNV FILE ? 1=YES  (1)
          1

LOWEST RESPONSE LOCATION NO. TO INCLUDE  (1)
          1

HIGHEST RESPONSE LOCATION NO. TO INCLUDE  (1000000)
     100000
```

```
SEQUENCE NO. TO READ IN [-1 = ALL]  (-1)
          1

ENTER TAPE1 FILE NAME TO RECEIVE DATA. [DEFAULT FILE TYPE = .DAT]
T1DEMO_NST5.DAT

SAVE THE COORDINATE-CODE INFORMATION IN A FILE ?  1=YES  (1)
          1

ENTER COORDINATE-CODE FILE NAME.  DEFAULT = TCDEMO_NST5.DAT
TCDEMO_NST5.DAT

WAS THIS FRF DATA GENERATED USING MODAL-PLUS [1] OR TDAS [2]  ?  (2)

[FOR AN N-POINT TIME HISTORY, TDAS GENERATES N/2 + 1 SPECTRAL LINES
 WHILE MPLUS GENERATES N/2.  THE LAST SPECTRAL LINE IN TDAS CONTAINS
 THE FMAX VALUE.  THIS DATA IS STORED IN THE IMAG. PART OF THE
 DC VALUE IN MODAL-PLUS.]
          2

FIRST RECORD NO. TO PROCESS ?  (1)
          1

LAST RECORD NO. TO PROCESS ?  (10000)
(ENTER A LARGE NUMBER TO READ ENTIRE FILE)
     100000

NTIM ? [NO. OF TIME PTS. TO WRITE OUT]  ( 5120)
 (ENTER A LARGE VALUE TO USE ALL AVAILABLE DATA)
     100000

REQUESTED NTIM IS GREATER THAN    5120, EXTRACTED FROM HEADER RECORD.
THE VALUE OF    5120 WILL BE USED INSTEAD.

USE ONLY THE IMAG. PART OF H(W) TO COMPUTE h(t) ? 1=YES  (0)
          0
```

RECORD	REF. COORD.	RES. COORD.	SEQ. NO.	# OF SPECTRAL LINES
1	201Z+	1X+	1	2561
2	201Z+	2X+	1	2561
3	201Z+	3X+	1	2561
4	201Z+	4X+	1	2561
5	201Z+	5X+	1	2561

```
END OF FILE ENCOUNTERED.

  NST  =            5
  NTIM =         5120
  SF   =  160.0000000
  FMIN =    0.0000000
```

```
5 RECORDS WRITTEN TO FILE T1DEMO_NST5.DAT
```

Note: Always write down the values of the four parameters printed at the end of the ERAP2 output (NST, NTIM, SF, and FMIN). These parameters characterize the data written to the Tape1 data file, and they must be specified later when ERA is run. NST is the total number of response stations (data records) contained in the file, NTIM is the number of time samples (data points) in each record, SF is the data sampling frequency in samples per second, and FMIN is the minimum frequency of bandlimited (zoom-transformed) data. Chapter 6 provides additional information on all ERA analysis parameters.

You **must** remember the SF and FMIN values printed at the end of the ERAP2 output listing. It is **impossible** to determine these values from the information recorded in the Tape1 data file. If necessary, however, the NST and NTIM values can be recovered from the Tape1 file by running program ERAP0, then entering 0 (the default) after specifying the Tape1 file name.

Two output files are created by program ERAP2. They are the "Tape1" data file and a corresponding "Coordinate-Code" file. These files are named T1DEMO_NST5.DAT and TCDEMO_NST5.DAT in this example. **You should always name ERA Tape1 data files beginning with "T1" and the corresponding Coordinate-Code file with the same name beginning with "TC".** The format of these ERA input files is described in Chapter 4.

File T1DEMO_NST5.DAT is a 201-block binary file containing five records of 5120 data points each.[91] File TCDEMO_NST5.DAT is a much smaller, 1-block ASCII file containing corresponding coordinate-code information for each data record in file T1DEMO_NST5.DAT. You can delete both of these files now. They are temporary files generated only to demonstrate the operation of program ERAP2.

[91]Tape1 data files always contain single-precision data which is adequate for experimental data.

3.2 Data Preview (ERAG1)

Data records on Tape1 files should be examined before running ERA. As a minimum, obvious errors in the data acquisition process can be detected and corrected. Even with high-quality data, however, there are other good reasons to examine the input data records before proceeding. These reasons include:

1. To estimate the number of modes in the bandwidth of interest.

2. To identify frequency intervals of unusually high modal density (modal clusters).

3. To estimate the level of damping.

4. To judge the effectiveness of various shaker locations to excite particular modes of interest.

5. To detect data inconsistencies in separate tests of the same structure, such as shifts in natural frequencies.

6. To check reciprocity of FRFs between pairs of excitation and response locations.

7. To estimate the signal-to-noise ratio of the data and its variation among the measurements.

8. To select an appropriate frequency bandwidth and/or time duration of data to be included in the analysis.

Program ERAG1 plots Tape1 data records in time- and/or frequency-domain formats. Time histories and corresponding frequency spectra are often plotted side-by-side. However, either histories or spectra can be plotted separately if desired. Any number of plots can be placed on each page, they can be drawn at any size, and multiple functions can be overlaid. Many other options are available to control the content and appearance of the plots.

All graphics pre- and post-processors (those whose names begin with "ERAG") use the public-domain graphics package DIGLIB developed at the Lawrence Livermore National Laboratory by Mr. Hal R. Brand.[92] DIGLIB is an acronym for "Device Independent Graphics Library." You can display DIGLIB plots on a variety of graphics devices. The specific device is selected at run time. To redirect the output to a different device (for example, from your terminal to a hard copy unit), simply rerun the program and change the

[92]A DIGLIB User's Guide is available in file ERA$DIGLIB:DIGLIB.DOC. It is not necessary to read the DIGLIB User's Guide to use the ERA software.

selection. This is done very quickly using the "GO Method" introduced in Section 3.1. The graphics device is selected by keyboard entry after all responses are read from the GO input file.

Now, program ERAG1 is demonstrated. Copy the GO input file named G1B_DEMO.COM from ERA$GO to your working directory as follows:

```
COPY ERA$GO:G1B_DEMO.COM []
```

Here is a listing of file G1B_DEMO.COM:

```
$! G1B_DEMO.COM
$!
$ RUN ERA$EXES:ERAG1
ERA$MMST_NAS:T1_MMST_NAS_SH2      TAPE1 FILENAME
74     FIRST RECORD TO PLOT
74     LAST RECORD TO PLOT
1      RECORD INCREMENT BETWEEN PLOTS
3      PLOT TYPE? 1=TIME, 2=FREQ, 3=BOTH
2      NO. OF PLOTS TO PLACE HORIZONTALLY ON PAGE
1      NO. OF PLOTS TO PLACE VERTICALLY ON PAGE
1      LINE STYLE?  1=SOLID, 2=SOLID & 3 DASHED (CYCLICALLY), 3=SOLID LINE...
1      LINEAR(0) OR LOG(1) SPECTRUM MAGNITUDE PLOT?
5      NO. OF DECADES TO USE ON FREQ. PLOT
0      VALUE FOR Y-AXIS MAX.  0=AUTOSCALE
0      HIGHLIGHT EACH DATA PT. ON SPECTRUM WITH A SYMBOL?  1=YES
1      INCLUDE COORDINATE CODES?  1=YES
160    SAMPLING FREQ., HZ
0      DATA FMIN
0      START TIME TO PLOT, SEC
32     FINAL TIME TO PLOT, SEC  [LARGE NO. TO PLOT COMPLETE HISTORY]
2      DELTA TIME (SEC.) FOR X-AXIS MINOR TIC MARKS.  0 = NONE
0       **   LINEAR(0) OR LOG(1) SCALE FOR TIME HISTORY Y-AXIS
0,0 IF **=0,MIN.,MAX. FOR TIME Y-AXIS. 0,0=AUTO. **=1,MAX.,NO. DECADES.0,-=AUTO
0      DELTA AMPL. FOR Y-AXIS MINOR TIC MARKS.  0 = NONE
0      HIGHLIGHT EACH DATA PT ON TIME HISTORY?  1=YES
0      STAIRSTEP TIME HISTORY PLOT? 1=YES
6      Y AXIS LABEL FOR TIME HISTORY. 1=T1DATA, 2=DISP IN IN., 3=DISP IN M, ...
       NO. OF POINTS TO FOURIER TRANSFORM (DEFAULT = ALL)
0      USE HANNING WINDOW?  1=YES
0      REMOVE DC VALUE?  1=YES
       FMIN TO PLOT (DEFAULT = DATA FMIN)
       FMAX TO PLOT (DEFAULT = SF/2 + DATA FMIN)
5      DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS
0.0    FREQ. FOR FIRST X-AXIS MINOR TIC MARK.  0.0 = ORIGIN OF PLOT
0      PLOT ABS(IMAG. PART) RATHER THAN MODULUS?  1=YES
0      SKIP SPECTRUM PHASE PLOT?  1=YES
1      INCLUDE X-AXIS GRID LINES ON FREQ. PLOT?  1=YES
1      ADD ADDITIONAL DOTTED VERTICAL LINES AT MINOR TICS?  1=YES
0.3    CHARACTER SIZE IN CM
1      FONT TYPE.  1=STICK, 2=BOLD LETTER QUALITY, 3=STD. LETTER QUALITY
```

```
0      PRINT OUT SPECTRUM TO FILE G1_SPECTRUM.OUT?  1=YES
1      USE DEFAULT OVERALL WINDOW SIZE?  1=YES
0      MODIFY DEFAULT AXIS NUMBERS?  1=YES
```

This file is similar to file P2_DEMO.COM discussed in Section 3.1 except with many more responses. **It would be very tedious indeed to enter all of these responses interactively**. Using GO, however, all that is necessary to run program ERAG1 is to edit a previous similar input file, and then type `GO filename`.

This example plots Record 74 from the Tape1 data file named T1_MMST_NAS_SH2.DAT. Record 74 is the driving point function for Shaker #2. Driving point FRFs provide a check on data quality because of their unique phase characteristic varying over only a 180-degree span. Accurate driving point FRFs are necessary to calculate modal masses (ref. Section 3.15).

Program ERAG1 generates time- and/or frequency-domain plots. In file G1B_DEMO.COM, the "3" appearing on line 8 selects both time- and frequency-domain functions. ***Note:*** *If the response to this question is either "1" for a time-domain plot, or "2" for a frequency-domain plot, the remaining questions asked by ERAG1 are somewhat different.* Thus, slightly different GO input files are necessary for time- or frequency-domain plots. The "B" in the name of this example file indicates that both time- and frequency-domain formats are requested. Other GO input files named G1T_DEMO.COM and G1F_DEMO.COM generate time- and frequency-domain plots alone. They are also available in directory ERA$GO.

To run G1B_DEMO.COM, enter:

```
GO G1B_DEMO
```

The following information appears on your computer screen when G1B_DEMO is run:

```
ERAG1.  PLOT TAPE1 DATA USING DIGLIB

TAPE1 FILENAME ? [DEFAULT FILE TYPE = .DAT]
ERA$MMST_NAS:T1_MMST_NAS_SH2

FIRST RECORD NO. TO PLOT ?  (1)
        74

LAST RECORD NO. TO PLOT ?  (1)
        74

RECORD INCREMENT BETWEEN PLOTS ?  (1)
         1

PLOT TYPE DESIRED ?  (3)
 1 = TIME-DOMAIN ONLY
```

```
 2 = FREQ-DOMAIN ONLY
 3 = BOTH
          3

NO. OF PLOTS TO PLACE HORIZONTALLY ON THE PAGE ?  (2)
          2

NO. OF PLOTS TO PLACE VERTICALLY ON THE PAGE ?  (2)
          1

LINE STYLE ?  (1)
 1 = SOLID LINES
 2 = 4 ALTERNATING LINE TYPES: SOLID & 3 TYPES OF DASHED LINES
 3 = SOLID ON LINE #1 ONLY; THEN 3 TYPES OF ALTERNATING DASHED LINES
          1

LINEAR(0) OR LOG(1) AXIS FOR SPECTRUM MAGNITUDE ?  (1)
          1

NO. OF DECADES TO SHOW ON SPECTRUM MAGNITUDE PLOT ?  (4)
          5

VALUE TO USE FOR Y-AXIS MAX. ON SPECTRUM MAGNITUDE PLOT ? 0=AUTOSCALE  (0)
 0.0000000E+00

HIGHLIGHT EACH DATA PT. ON SPECTRUM WITH A SYMBOL ?  1=YES.  (0)
          0

INCLUDE COORDINATE CODES ON PLOT ?  1=YES.  (1)
          1

ENTER SF [SAMPLING FREQUENCY IN HERTZ] ?  (100.)
  160.0000

DATA FMIN ? [> 0 FOR ZOOMED DATA]  (0.)
 0.0000000E+00

   5120 TOTAL AVAILABLE TIME SAMPLES =   31.994 SECONDS

START TIME TO PLOT ?  (     0.000)
 0.0000000E+00

FINAL TIME TO PLOT ?  (   31.994)
  32.00000

REQUESTED FINAL TIME IS GREATER THAN THE AVAILABLE
DATA LENGTH.  FINAL TIME REDUCED TO   31.994

DELTA TIME (SEC.) FOR X-AXIS MINOR TIC MARKS ? 0 = NONE  (0.5)
  2.000000

PLOT TIME HISTORY USING LINEAR(0) OR LOG(1) Y-AXIS ? (0)
          0
```

```
MINIMUM & MAXIMUM VALUES FOR TIME HISTORY Y-AXIS ?  0,0 = AUTOSCALE
 0.0000000E+00  0.0000000E+00

DELTA AMPL. FOR Y-AXIS MINOR TIC MARKS ON TIME HISTORIES ? 0 = NONE  (1.0)
 0.0000000E+00

HIGHLIGHT EACH DATA PT. ON TIME HISTORIES WITH A SYMBOL ?  1=YES  (0)
          0

STAIRSTEP TIME HISTORY PLOT ?  1=YES  (0)
          0

SELECT Y AXIS LABEL FOR TIME HISTORY PLOT:  (1)
 0. USER SUPPLIED
 1. T1DATA
 2. DISPLACEMENT IN INCHES
 3. DISPLACEMENT IN METERS
 4. ACCELERATION IN G'S
 5. ACCELERATION IN M/SEC^2
 6. IMPULSE RESPONSE
 7. PULSE RESPONSE
 8. ACCEL. RESPONSE, CM/SEC^2
 9. FORCE, LBS
          6

ENTER NO. OF TIME SAMPLES TO FOURIER TRANSFORM ?  (  5120)
[ANY VALUE PERMITTED; SUBROUTINE SFT IS NOT RESTRICTED TO ONLY POWERS-OF-2]
       5120

USE HANNING WINDOW ? 1=YES.  (0)
          0

REMOVE DC VALUE ?  1=YES.  (0)
          0

FMIN TO PLOT ?  (  0.000)
 0.0000000E+00

FMAX TO PLOT ? (   80.000)
  80.00000

DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS ? 0=NONE  (1.0)
  5.000000

FREQ. OF FIRST X-AXIS MINOR TIC MARK ?  0.0 = ORIGIN OF PLOT. (0.0)
 0.0000000E+00

PLOT ABS(IMAG. PART) RATHER THAN MODULUS ?  1=YES.  (0)
          0

SKIP SPECTRUM PHASE PLOT ?  1=YES  (0)
          0

INCLUDE X-AXIS GRID LINES ON FREQ-DOMAIN PLOT
```

```
(AT EACH MAJOR TIC) ?  1=YES  (1)
          1

ALSO ADD ADDITIONAL DOTTED VERTICAL LINES AT MINOR TIC MARKS ?  1=YES.  (1)
          1

CHARACTER SIZE (HT.) FOR PLOT LABELS, IN CM ?  (0.3)
 0.3000000

FONT TYPE ?  (1)
 1 = STICK FONT
 2 = LETTER QUALITY - BOLD
 3 = LETTER QUALITY - STD.
          1

PRINT OUT SPECTRUM TO FILE G1_SPECTRUM.OUT ?  1=YES  (0)
          0

USE THE DEFAULT OVERALL WINDOW SIZE ? 1=YES  (1)
          1

MODIFY DEFAULT AXIS NUMBERS ?  1=YES  (0)
          0

GRAPHICS DEVICE NUMBER ?  (4)
  1 = TEK. 4010
  2 = TEK. 4014
  3 = TEK. 4025
  4 = TEK. 4107
  5 = TEK. 4115B
  6 = HP 2647/2648
  7 = DEC VT240
  8 = HPGL TALL
  9 = HPGL WIDE
 10 = POSTSCRIPT TALL
 11 = POSTSCRIPT WIDE
```

After all questions and responses scroll by, ERAG1 pauses at the question "GRAPHICS DEVICE NUMBER ?". You select the graphics device at this time. **To simplify entering responses for any pre- or post-processor, a default value is shown in parentheses after most questions. The default value is selected by simply pressing RETURN.** For example, the default graphics device (4 = Tektronix 4107) is selected by pressing the return key when the list of choices is displayed. In GO input files, the default value is selected by leaving one or more blank spaces at the beginning of a response line.

If you select graphics device No. 10 or 11 (PostScript), the following additional question appears:

```
USE DEFAULT PLOT PARAMETERS ?  1=YES  (1)
```

Entering any number other than "1" permits changes to be made in the x,y magnification factors and line width of the plot. These characteristics (particularly the magnification factors) are often varied when hard copies of reduced size are generated for technical reports. Magnification factors less than 1.0 reduce the image size relative to full page size.

The appearance of graphics output varies slightly depending on the graphics device selected. **Fig. 3-2** shows the plot generated when G1B_DEMO is run using Graphics Device #11 (PostScript Wide).

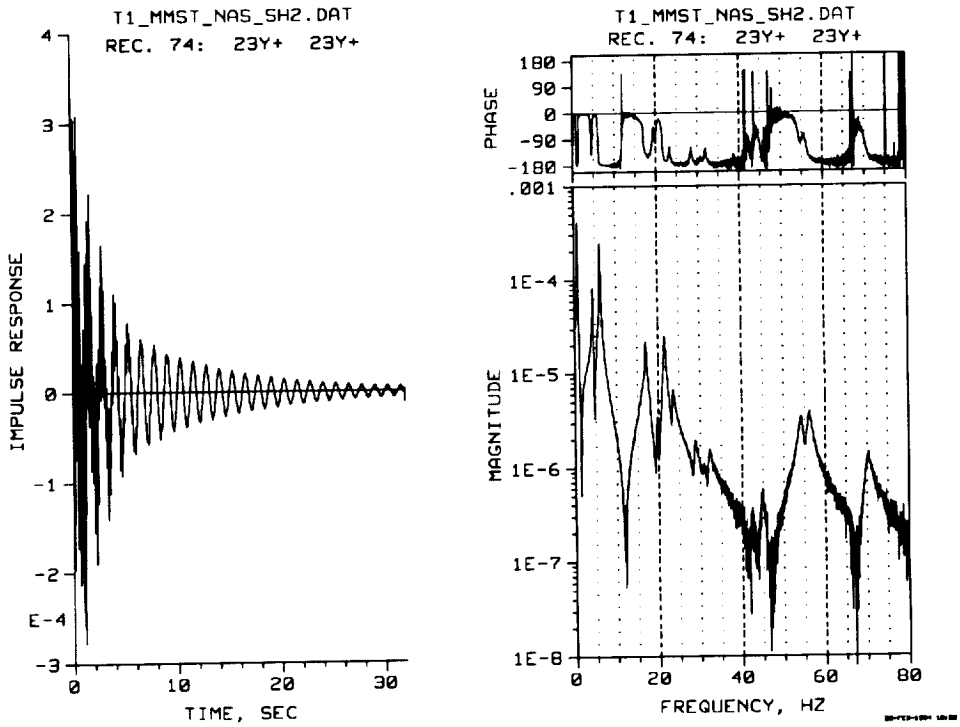


Fig. 3-2. Driving-Point IRF and FRF for Shaker 2 [G1B_DEMO][93]

The time history shown on the lefthand side of Fig. 3-2 is the data stored in the Tape1 file. The frequency spectrum on the righthand side is obtained from the time history using a fast Fourier transform (FFT). *The FFT routine in all ERA pre- and post-processors (named SFT) permits any number of data points to be transformed.* In this example, 5120 data points are transformed. Whenever program ERAG1 plots both time histories and frequency spectra, the time history is always plotted first, followed by the corresponding spectrum.

[93]The name in brackets in figure titles is the name of the GO Input file which generates the figure.

The "23Y+ 23Y+" at the top of the plots are the excitation and response coordinate codes, respectively.

If multiple pages of graphics output are generated (e.g., by modifying file G1B_DEMO.COM to plot Records 74 and 75) and you display the output on a graphics terminal (Device Nos. 1 - 7), a pause occurs after each page. Press RETURN to continue. You may abort plotting at any time by entering Ctrl Y.

Program ERAG1 plots data from only a single Tape1 file. Section 12.12 demonstrates a procedure for combining data records from multiple Tape1 files into a temporary file for ERAG1.

The peaks in the spectrum of Fig. 3-2 can be compared with the true, NASTRAN natural frequencies. Section 12.13 demonstrates a procedure for listing the NASTRAN frequencies from the mode shape .UNV file.

3.3 Digital Filtering (ERAP20)

Because of the large number of modes in the 0 to 80 Hz bandwidth (140), a single ERA analysis requires an unusually large Hankel matrix size (ref. Section 2.3). It is generally more efficient to filter such data into narrower frequency bands to reduce the number of modes handled simultaneously. Each filtered data set is analyzed separately. A disadvantage of performing several smaller analyses rather than one large analysis, however, is the increased data handling required. However, several small analyses normally require much less computer time than one large analysis. In practice, data are typically filtered to include a maximum of approximately 30 modes.

Pre-processor program ERAP20 performs frequency-domain digital filtering by Fourier transforming Tape1 time-domain data, extracting a selected frequency interval, then inverse Fourier transforming to obtain bandlimited time histories.[94] With typical structural dynamics data having modal damping of a few percent or less, this approach causes negligible distortion of the identification results except for modes located near the selected upper and lower frequency limits.[95]

---

[94]Time-domain FIR digital filtering of Tape1 data is also available using the new pre-processor program ERAP21. (FIR = finite impulse response.) **The capabilities of ERAP21 are also integrated into the ERA code using analysis parameters FR1FIR, FR2FIR, and IORFIR (see Chapter 6). The capabilities of ERAP20 are not yet integrated into the ERA code.**

[95]IRF distortion due to the truncated tails of in-bandwidth modes is reduced somewhat using a new approach for computing the IRF using only the imaginary part of the FRF. This option is available in programs ERAP2 and ERAP20. The method is described in Ref. 12.

GO input files named P20_SH*a*_*b*_*c*_DEMO.COM are available in directory ERA$GO to filter the Tape1 data files for this demonstration problem, where *a* = shaker number (1, 2, or 3), *b* = lower frequency limit (Hz), and *c* = upper frequency limit (Hz). The Tape1 data files are filtered in 3 frequency bands: 0 - 10 Hz, 20 - 50 Hz, and 50 - 80 Hz. These selections skip the cluster of 108 local modes (due to the bending of individual truss members) in the frequency interval of 10 - 20 Hz. The filtering process generates a total of 9 new Tape1 files (3 shakers x 3 frequency ranges).

The VMS command procedure named P20_ALL_DEMO.COM executes all 9 of these "P20" GO input files automatically. First, SET DEFAULT back to your [.DEMO] directory if you are not already there. Then, copy and execute file P20_ALL_DEMO.COM as follows:

```
COPY ERA$GO:P20_ALL_DEMO.COM []

@P20_ALL_DEMO
```

Be sure to use the standard VMS "@" command to execute this file, not "GO."

Here is a listing of file P20_ALL_DEMO.COM:

```
$! P20_ALL_DEMO.COM
$!
$ SET VERIFY
$!
$ COPY ERA$GO:P20_SH1_0_10_DEMO.COM []
$ COPY ERA$GO:P20_SH2_0_10_DEMO.COM []
$ COPY ERA$GO:P20_SH3_0_10_DEMO.COM []
$!
$ COPY ERA$GO:P20_SH1_20_50_DEMO.COM []
$ COPY ERA$GO:P20_SH2_20_50_DEMO.COM []
$ COPY ERA$GO:P20_SH3_20_50_DEMO.COM []
$!
$ COPY ERA$GO:P20_SH1_50_80_DEMO.COM []
$ COPY ERA$GO:P20_SH2_50_80_DEMO.COM []
$ COPY ERA$GO:P20_SH3_50_80_DEMO.COM []
$!
$ GO P20_SH1_0_10_DEMO
$ GO P20_SH2_0_10_DEMO
$ GO P20_SH3_0_10_DEMO
$!
$ GO P20_SH1_20_50_DEMO
$ GO P20_SH2_20_50_DEMO
$ GO P20_SH3_20_50_DEMO
$!
$ GO P20_SH1_50_80_DEMO
$ GO P20_SH2_50_80_DEMO
$ GO P20_SH3_50_80_DEMO
$!
$ SET NOVERIFY
```

This procedure copies all 9 GO input files from directory ERA$GO into your default directory and then executes them sequentially. Execution requires approximately 10 minutes of CPU time on the author's VAXstation 3100 to generate the 9 filtered Tape1 files.

Here is a listing of the first of the 9 GO input files, file P20_SH1_0_10_DEMO.COM:

```
$! P20_SH1_0_10_DEMO.COM
$!
$ RUN ERA$EXES:ERAP20
ERA$MMST_NAS:T1_MMST_NAS_SH1  TAPE1  INPUT FILE NAME     (T1xxx)
T1_MMST_NAS_SH1_0_10          TAPE1 OUTPUT FILE NAME     (T1yyy)
1       COORDINATE CODE FILE?  1=YES
        COORDINATE CODE INPUT FILE NAME  (DEFAULT = TCxxx)
        COORDINATE CODE OUTPUT FILE NAME (DEFAULT = TCyyy)
0       NST  FOR DATA ON INPUT FILE.  0 = ALL
0       NTIM FOR DATA ON INPUT FILE.  0 = ALL
160     SAMPLING FREQUENCY IN HZ?
0       FMIN OF DATA ON INPUT FILE  (ORIGINAL)
0       FMIN OF FILTERED DATA (OUTPUT)
10      FMAX OF FILTERED DATA (OUTPUT)
1       REDUCE NO. OF FREQ. LINES TO THOSE IN THE FILTERED INTERVAL? 1=YES
0       USE ONLY IMAG. PART OF H(W) TO COMPUTE h(t) ?  1=YES
```

The following information appears on your computer screen when file P20_SH1_0_10_DEMO.COM is run. The information displayed for the other 8 input files is similar.

```
ERAP20.  DIGITALLY FILTER TAPE1 BY FFT/ZEROING/IFFT.

ENTER INPUT TAPE1 FILE NAME  [DEFAULT FILE TYPE = .DAT]
ERA$MMST_NAS:T1_MMST_NAS_SH1.DAT


ENTER OUTPUT TAPE1 FILE NAME  [DEFAULT FILE TYPE = .DAT]
T1_MMST_NAS_SH1_0_10.DAT


SHOULD A COORDINATE-CODE FILE BE GENERATED ? 1=YES  (1)
          1

INPUT COORDINATE-CODE FILE NAME ?
  DEFAULT = TC_MMST_NAS_SH1.DAT

TC_MMST_NAS_SH1.DAT


OUTPUT COORDINATE-CODE FILE NAME ?
  DEFAULT = TC_MMST_NAS_SH1_0_10.DAT

TC_MMST_NAS_SH1_0_10.DAT
```

```
NST FOR DATA ON TAPE1 ? [0 = COMPLETE FILE]   (0)
          0

NTIM FOR DATA ON TAPE1 ? [0 = PROGRAM DETERMINES]   (0)
          0

NTIM =  5120

SF OF DATA ?  (100.0)
  160.0000

FMIN OF DATA ?  (0.0)
 0.0000000E+00

FMIN TO RETAIN ?  (      0.000)
 0.0000000E+00

FMAX TO RETAIN ?  (     80.000)
  10.00000

FIRST & LAST FREQ. LINES TO BE RETAINED:       0    320

REDUCE NO. OF FREQ. PTS TO THOSE IN THIS INTERVAL ALONE? 1=YES   (1)
          1

USE ONLY THE IMAG. PART OF H(W) TO COMPUTE h(t) ? 1=YES   (0)
          0
```

RECORD	REF. COORD.	RES. COORD.
1	201Z+	1X+
2	201Z+	2X+
3	201Z+	3X+
4	201Z+	4X+
5	201Z+	5X+
6	201Z+	6X+
7	201Z+	7X+
8	201Z+	8X+
9	201Z+	9X+
10	201Z+	10X+
11	201Z+	11X+
12	201Z+	12X+
13	201Z+	13X+
14	201Z+	14X+
15	201Z+	15X+
16	201Z+	16X+
17	201Z+	17X+
18	201Z+	18X+
19	201Z+	19X+
20	201Z+	20X+
21	201Z+	21X+

22	201Z+	22X+
23	201Z+	23X+
24	201Z+	24X+
25	201Z+	25X+
26	201Z+	26X+
27	201Z+	27X+
28	201Z+	28X+
29	201Z+	29X+
30	201Z+	30X+
31	201Z+	31X+
32	201Z+	32X+
33	201Z+	33X+
34	201Z+	34X+
35	201Z+	35X+
36	201Z+	36X+
37	201Z+	37X+
38	201Z+	38X+
39	201Z+	39X+
40	201Z+	40X+
41	201Z+	41X+
42	201Z+	42X+
43	201Z+	43X+
44	201Z+	44X+
45	201Z+	45X+
46	201Z+	46X+
47	201Z+	47X+
48	201Z+	48X+
49	201Z+	49X+
50	201Z+	50X+
51	201Z+	51X+
52	201Z+	1Y+
53	201Z+	2Y+
54	201Z+	3Y+
55	201Z+	4Y+
56	201Z+	5Y+
57	201Z+	6Y+
58	201Z+	7Y+
59	201Z+	8Y+
60	201Z+	9Y+
61	201Z+	10Y+
62	201Z+	11Y+
63	201Z+	12Y+
64	201Z+	13Y+
65	201Z+	14Y+
66	201Z+	15Y+
67	201Z+	16Y+
68	201Z+	17Y+
69	201Z+	18Y+
70	201Z+	19Y+
71	201Z+	20Y+
72	201Z+	21Y+
73	201Z+	22Y+
74	201Z+	23Y+
75	201Z+	24Y+

```
    76        201Z+          25Y+
    77        201Z+          26Y+
    78        201Z+          27Y+
    79        201Z+          28Y+
    80        201Z+          29Y+
    81        201Z+          30Y+
    82        201Z+          31Y+
    83        201Z+          32Y+
    84        201Z+          33Y+
    85        201Z+          34Y+
    86        201Z+          35Y+
    87        201Z+          36Y+
    88        201Z+          37Y+
    89        201Z+          38Y+
    90        201Z+          39Y+
    91        201Z+          40Y+
    92        201Z+          41Y+
    93        201Z+          42Y+
    94        201Z+          43Y+
    95        201Z+          44Y+
    96        201Z+          45Y+
    97        201Z+          46Y+
    98        201Z+          47Y+
    99        201Z+          48Y+
   100        201Z+          49Y+
   101        201Z+          50Y+
   102        201Z+          51Y+
   103        201Z+         201Z+
   104        201Z+         203Z+

END-OF-FILE ENCOUNTERED


FILTERED DATA WRITTEN TO FILE T1_MMST_NAS_SH1_0_10.DAT


  NST  =          104
  NTIM =          640
  SF   =    20.0000000
  FMIN =     0.0000000
```

Note: Always write down the values of the four parameters shown above (NST, NTIM, SF, and FMIN). These values characterize the data written to the Tape1 data file, and they must be specified later when ERA is run. NST is the total number of response stations (data records) contained in the file, NTIM is the number of time samples (data points) in each record, SF is the data sampling frequency in samples per second, and FMIN is the minimum frequency of bandlimited (zoom-transformed) data. Chapter 6 provides additional information on all analysis parameters.

Warning

You must remember the SF and FMIN values printed at the end of the ERAP20 output listing. It is **impossible** to determine these values from the information recorded in the Tape1 data file. If necessary, however, the NST and NTIM values are recoverable from the Tape1 file by running program ERAP0, then entering 0 (the default) after specifying the Tape1 file name.

The transformation of bandlimited frequency response functions (FRFs) into impulse response functions (IRFs) using program ERAP20 calculates a fictitious sampling frequency based on the bandwidth of the FRFs. The transformation does not affect the damping rates ($\sigma = -\zeta\omega_n$). Using **Fig. 3-3** as an example (plotted with GO input file G1B_20_50_DEMO.COM), this distortion is explained as follows. The first peak in the FRF occurs at approximately 1.6 Hz after the initial frequency of 20 Hz. The associated cycle time is the reciprocal of 1.6 Hz or 0.625 sec. This cycle time occurs in the IRF for the dominant oscillation. However, the correct frequency of this peak is, in fact, 21.6 Hz corresponding to a cycle time of 0.046 sec. During analysis, the ERA software eliminates this distortion by adding the initial frequency to the frequency results. It then adjusts the computed damping factors, ζ. The sampling frequency of IRFs always equals twice the bandwidth of the corresponding FRF (in this example, SF = 2 * (50 - 20) = 60 Hz). The number of time samples in IRFs always equals twice the number of frequency lines in the corresponding FRF (in this example, NTIM = 2 * 960 = 1920).

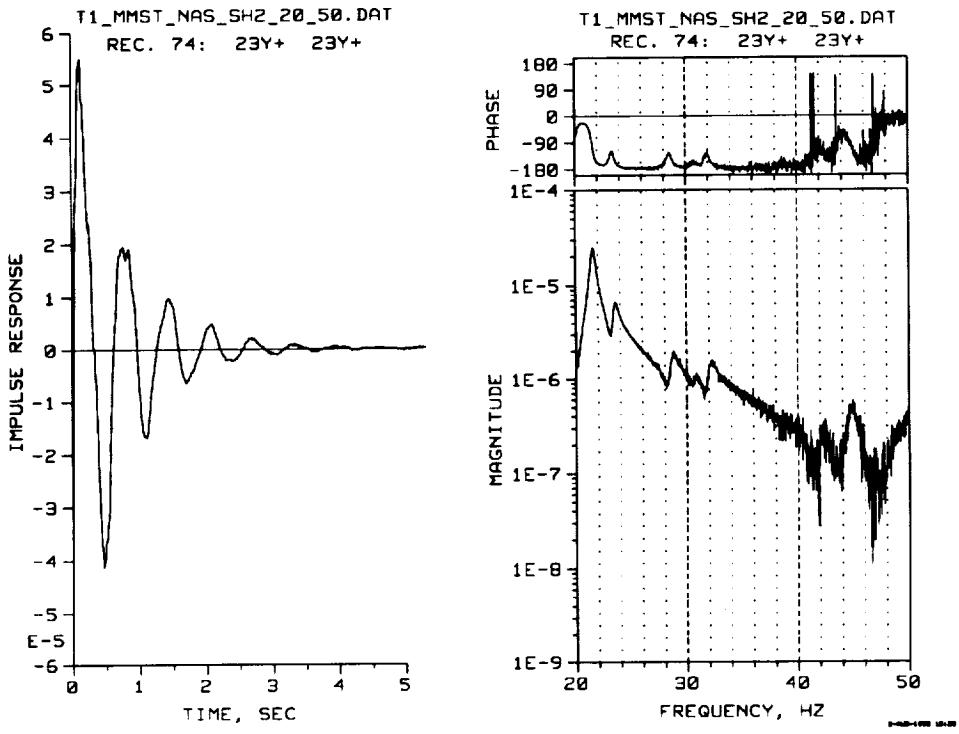


Fig. 3-3. Digitally Filtered Driving-Point IRF and FRF for Shaker 2 [G1B_20_50_DEMO]

For comparison purposes, you can also filter the data record shown in Fig. 3-2 using time-domain FIR filtering (program ERAP21). FIR is an acronym for "finite impulse response." GO input file P21_20_50_DEMO.COM is available in directory ERA$GO for this purpose. It uses a 50th-order bandpass filter from 20 Hz to 50 Hz. Use file G1B_FIR_20_50_DEMO.COM to plot the resulting filtered time history. The FIR filtering procedure of program ERAP21 does not affect the Tape1 data sampling frequency (in this example, SF = 160 Hz for both the original and filtered Tape1 files).

3.4 Selecting ERA Analysis Parameters

Initial analyses of the three data sets of this demonstration problem (0-10 Hz, 20-50 Hz, and 50-80 Hz) use default analysis parameters. All that is required by the user is selection of the size of the ERA generalized Hankel matrices, specified by parameters NCH and NRH. NCH is the total number of columns in the Hankel matrices, and NRH is the total number of rows.[96]

[96]Appendix I gives general guidelines for selecting NCH and NRH. Chapter 6 describes all available analysis parameters.

With low-noise, linear data as in this demonstration problem, the only requirement on the Hankel matrix size is that it be "large enough." Theoretically, each dimension of the matrix can be no smaller than twice the number of modes comprising the data.[97] Additionally, the number of columns in the matrix should generally be no smaller than twice the number of inputs (NCH >= 2 * NIC) and the number of rows in the matrix no smaller than twice the number of outputs (NRH >= 2 * NST).[98]

This demonstration problem uses impulse response data obtained by inverse Fourier transformation of bandlimited frequency response functions. Due to contributions from modes outside the retained data bandwidth, a minimum Hankel matrix size is inadequate. A larger matrix size is necessary to permit identification of additional "computational modes" (mostly real eigenvalues) compensating for these effects. Additional computational modes are also necessary because of truncation in frequency of the FRFs of modes within the retained bandwidth (the complete FRF of every mode extends from 0 Hz to infinity). **Fig. 3-4** illustrates these 2 types of truncation errors. With typical structural dynamics data having modal damping of a few percent or less, these errors have negligible effect on the identified modal parameters except for modes located near the edges of the analysis bandwidth.[99]

---

[97]You must satisfy this requirement to identify ALL modes. However, if the minimum dimension of the Hankel matrix is less than twice the number of modes, you may still accurately identify modes with the largest amplitudes. In practice, the precise number of modes is often uncertain.

[98]When the number of response measurements (NST) is >> the number of modes in the analysis bandwidth, NRH can be much less than 2 * NST using the KEYDTA option discussed in Section 3.14.

[99]IRF distortion due to the truncated tails of in-bandwidth modes is reduced somewhat using a new approach for computing the IRF using only the imaginary part of the FRF. This option is available in programs ERAP2 and ERAP20. The method is described in Ref. 12.

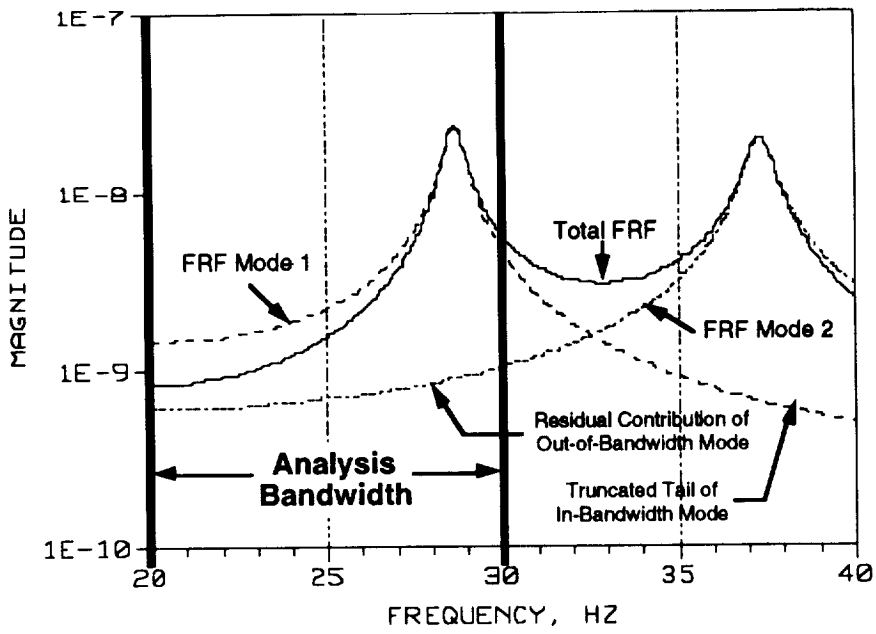


Fig. 3-4. Truncation Errors With Bandlimited FRF Data

When selecting analysis parameters NCH and NRH, it is preferable to use multiples of NIC and NST, respectively, where NIC is the number of inputs (initial conditions) and NST is the number of outputs (response stations). This approach permits the Extended Modal Amplitude Coherence, EMAC (Ref. 8 and Section 2.6.2), to be computed for every input and output. EMAC measures the temporal consistency of the identified modal parameters. The software permits all values of NCH and NRH; however, it cannot calculate EMAC for every input and output if NCH and NRH are not multiples of NIC and NST, respectively. ERA issues a warning message if you specify non-multiple values of NCH and/or NRH.[100] Following the warning message, the software gives a recommended value of NCH and/or NRH.

Using the knowledge that 5 modes occur in the 0-10 Hz bandwidth, 13 modes occur in the 20-50 Hz bandwidth, and 11 modes occur in the 50-80 Hz bandwidth (you can also estimate this information from spectra such as Fig. 3-2), the initial analyses of the 3 data sets will use NCH values of 51, 81, and 75, respectively. Standard operating procedure selects NCH (much) smaller than NRH whenever NIC is (much) smaller than NST. Under these conditions, NCH is the smaller dimension of the Hankel matrix. The smaller dimension primarily determines computer time requirements. The most time consuming step of ERA is usually the singular-value-decomposition (SVD) step consisting of $2pq^2 + 4q^3$ floating point operations, where $q \leq p$ are the dimensions of the Hankel data matrix. Therefore, when NCH << NRH, the value of NRH affects CPU time requirements

[100]All warning and fatal error messages are written on the "Tape50" output file.

relatively little. In this demonstration problem, each initial analysis uses an NRH value of 520 (5 x NST) .

Analysis parameters NCH and NRH are selected by specifying parameters MCH and MRH in the ERA "User Input file" (see Section 4.1). MCH and MRH are the maximum values that parameters NCH and NRH, respectively, can have during a single job. Parameters MCH and MRH are FORTRAN array dimensions. **By default, NCH equals MCH, and NRH equals MRH.** *This is the standard method of specifying parameters NCH and NRH; i.e., by specifying MCH and MRH in Field 3 of the User Input file.*

The User Input file for the initial analysis of the 20-50 Hz data appears below. The file name is INIT_20_50.ERA and the corresponding jobname is INIT_20_50.[101] The User Input files for the 2 other data sets are identical except for changes in parameters MCH, MTIM (the number of time samples in each data record of the Tape1 files), SF (the data sampling frequency = twice the data bandwidth), and FMIN (the minimum frequency of the data bandwidth for bandlimited data). All user inputs required to run Job INIT_20_50 are highlighted in bold type. File INIT_20_50.ERA is stored in directory ERA$MMST_NAS.

```
$! INIT_20_50.ERA
$!
$! INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$   [PAPPA.DEMO]
$ DEFINE ERA_OUTPUT$ [PAPPA.DEMO]
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=INIT_20_50
$!
$ INPUT1:=_MMST_NAS_SH1_20_50
$ INPUT2:=_MMST_NAS_SH2_20_50
$ INPUT3:=_MMST_NAS_SH3_20_50
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=81/
S/MRH=/MRH=520/
```

[101] Job names are given in Field 2 of the User Input file. The job name can be no longer than 26 characters.

```
S/MIC=/MIC=3/
S/MST=/MST=104/
S/MTIM=/MTIM=1920/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
  SF=60.,FMIN=20.
  ITAPES=51,55,79,88,T88CMI=0.
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!             [ALWAYS USE EXACTLY 5 LINES]
$!
  LINE 1 FOR COMMENTS
  INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
  FILTERED DATA: 20 - 50 HZ
  USING DEFAULT S.V. CUTOFF
  INIT_20_50:
```

All analysis parameters except MCH, MRH, MIC, MST, and MTIM are declared using FORTRAN NAMELIST format in Field 4 of the User Input file. Specify only those parameters you wish to change. All others retain their default values. **The beginning of every Tape50 output file (ref. Section 3.6) contains a complete list of all analysis parameters and their default values.** Section 3.6 discusses the contents of the Tape50 file. Chapter 6 describes all ERA analysis parameters.

Parameter SF, the data sampling frequency in samples per second, must be specified in every analysis. In this demonstration problem, 3 other analysis parameters are also given: FMIN, ITAPES, and T88CMI.[102] FMIN is the minimum frequency in Hz of bandlimited (zoom-transformed) data. Parameter ITAPES activates various output files. In this case, all 4 optional output files (Tapes 51, 55, 79, and 88) are activated.[103] Tape51 contains the identified mode shapes in "printer-plot" format, Tape55 contains a detailed listing of accuracy indicator values (EMAC) on an input-by-input and output-by-output basis useful for selecting KEYDTA (ref. Section 3.14), Tape79 contains the identification results in MATRIXx format[104], and Tape88 contains the identified mode shapes in SDRC Universal File format. Parameter ITAPES is an array variable that accepts multiple values separated by commas. The values can appear in any order. Parameter T88CMI (a scalar variable) specifies the minimum CMI value of modes written to Tape88. Only modes having CMI values of at least T88CMI percent appear on Tape88. The default value of T88CMI is 1

[102] All ERA parameter names follow the FORTRAN 77 convention concerning integer and real variables; i.e., names beginning with letters I through N specify integer quantities and all others specify real quantities.

[103] Output files Tape50 and Tape85 are activated by default.

[104] Post-processor ERAP79 converts Tape79 to MATLAB binary .MAT format.

percent. In this demonstration problem, a T88CMI value of 0 causes all identified mode shapes to be saved.

3.5 Running ERA

ERA is a batch program.[105] All parameters required for each job are specified in a "User Input file" prior to execution. No additional inputs occur during program execution.

Execute ERA in one of the following three ways:

1. To execute ERA as a batch job, enter the following command:

```
ERA fname
```

where **fname** is the name of the User Input file. *The User Input file,* **fname**, *is assumed to reside in your current default directory.* The default file type for User Input files is **.ERA**. To differentiate ERA User Input files, it is highly recommended that file type **.ERA** be used. The jobname specified in Field 2 of the User Input file is normally used for filename **fname**, although this is not mandatory.

The following message appears on your computer screen when ERA is executed as a batch job:

```
Job ERA (queue SYS$BATCH, entry xx) started on SYS$BATCH
```

If file **fname** does not exist in your current default directory, you will receive the following error message shortly after entering the **ERA fname** command:

```
Job ERA (queue SYS$BATCH, entry xx) completed
  %COPY-E-OPENIN, error opening !AS as input
```

The **ERA** command submits the job to a batch queue named ERA_BATCH_QUEUE. By default, this logical name is assigned to queue SYS$BATCH. Your system manager can assign ERA_BATCH_QUEUE to a different queue, or he can establish symbols that allow you to switch queues easily.

When ERA executes as a batch job, your terminal is available for other purposes while the job runs. A message and beep are sent to your terminal when the job finishes. You can monitor the cumulative CPU time of the job during its execution using the VMS SHOW SYSTEM/BATCH command. A batch job continues to run if you log off the computer.

---

[105]Program execution is controlled by a VMS command procedure that executes with no user interaction. This command procedure can be submitted as a batch job, run interactively, or spawned as a subprocess.

Multiple ERA jobs can execute simultaneously if they have different Jobnames as defined in the Field 2 of the User Input file. Although each job creates several temporary files, unique names ensure that multiple jobs do not interact. The system deletes all temporary files at the end of a successful run. If the job aborts prematurely, however, these temporary files will remain in your directory. All temporary files have file type .TMP, and you must delete them yourself.

Multiple ERA jobs running simultaneously can access the same Tape1 and Coordinate-Code input files. Each job opens the file(s) using the READONLY qualifier on the FORTRAN OPEN statement so that multiple, simultaneous access is permitted.

It is impossible, however, to simultaneously run 2 ERA jobs having the same Jobname.

If you use the same Jobname as in a previous ERA run, the output files of the second job replace those of the first job.

With batch execution, you can examine ERA output files during execution using the VMS TYPE or EDIT/READ_ONLY commands.

2. To execute ERA as an interactive job, enter the following command:

```
@ERA fname
```

where **fname** is the name of the User Input file. *The User Input File,* **fname**, *is assumed to reside in your current default directory.*

When ERA runs interactively, your terminal is locked and cannot be used for other purposes. You must abort ERA or open another window (if your terminal supports this feature) to perform other work. Running ERA interactively is generally the fastest method because VMS assigns high priority to interactive processes.

3. To spawn ERA as a subprocess, enter the following command:

```
SPNERA fname
```

where **fname** is the name of the User Input file. *The User Input File,* **fname**, *is assumed to reside in your current default directory.*

This method permits your terminal to be used for other purposes while achieving the same priority as an interactive job. On many VAX systems, however, spawned jobs are not permitted (or are discouraged) by the system manager to limit the number of high-priority jobs.

Warning

Spawned jobs are *terminated* if you LOG OFF.

You should now run each of the initial ERA analyses for the demonstration problem using any of the 3 techniques described above. Before running these jobs, however, the input and output directory names specified in Field 1 of the ERA User Input files must be changed. These names are currently defined as [PAPPA.DEMO]. Change these directory names to those you are using for this demonstration problem. The Input directory (logical name ERA_INPUT$) is the directory from which ERA reads the Tape1 and Coordinate-Code files. The Output directory (logical name ERA_OUTPUT$) is the directory into which ERA writes all output files. If you specify a directory using a VMS logical name, the logical name must be terminated with a colon.

The User Input files for this demonstration problem are named INIT_0_10.ERA, INIT_20_50.ERA, and INIT_50_80.ERA for analysis of the 0-10 Hz data, 20-50 Hz data, and 50-80 Hz data, respectively. The files are stored in directory ERA$MMST_NAS. Copy them into your working directory, edit the input and output directory names as described above, then execute each job. The following CPU times are required for execution on the author's VAXstation 3100:[106]

Job INIT_0_10:	23 secs.
Job INIT_20_50:	57 secs.
Job INIT_50_80:	56 secs.

[106]CPU time is printed at the end of every Tape50 output file.

Each of these 3 jobs will generate 6 output files named 50jobname, 51jobname, 55jobname, 79jobname, 85jobname, and 88jobname. These files are referred to as the "Tape50 file," the "Tape51 file," etc. This terminology is a carry-over from use on CDC computers where the default file name assigned to FORTRAN logical unit n is TAPEn. A complete description of each output file is available in Chapter 5. If you issue the following VMS DIRECTORY command, the 21 files listed below should exist in your working directory after all 3 jobs have been run:

```
$ DIRECTORY/SIZE *INIT*

Directory SDBRP$DKA0:[PAPPA.DEMO]

50INIT_0_10.LIS;1          52  23-FEB-1994 16:02:21.15  [PAPPA]
50INIT_20_50.LIS;1         70  23-FEB-1994 15:55:16.52  [PAPPA]
50INIT_50_80.LIS;1         70  23-FEB-1994 16:03:30.60  [PAPPA]
51INIT_0_10.LIS;1         277  23-FEB-1994 16:02:21.39  [PAPPA]
51INIT_20_50.LIS;1        660  23-FEB-1994 15:55:16.78  [PAPPA]
51INIT_50_80.LIS;1        715  23-FEB-1994 16:03:30.86  [PAPPA]
55INIT_0_10.LIS;1          48  23-FEB-1994 16:02:21.66  [PAPPA]
55INIT_20_50.LIS;1         76  23-FEB-1994 15:55:17.03  [PAPPA]
55INIT_50_80.LIS;1         60  23-FEB-1994 16:03:31.10  [PAPPA]
79INIT_0_10.DAT;1         127  23-FEB-1994 16:02:22.39  [PAPPA]
79INIT_20_50.DAT;1        271  23-FEB-1994 15:55:17.71  [PAPPA]
79INIT_50_80.DAT;1        326  23-FEB-1994 16:03:31.81  [PAPPA]
85INIT_0_10.LIS;1           6  23-FEB-1994 16:02:20.57  [PAPPA]
85INIT_20_50.LIS;1          8  23-FEB-1994 15:55:16.23  [PAPPA]
85INIT_50_80.LIS;1          8  23-FEB-1994 16:03:30.34  [PAPPA]
88INIT_0_10.UNV;1          53  23-FEB-1994 16:02:22.69  [PAPPA]
88INIT_20_50.UNV;1        126  23-FEB-1994 15:55:18.00  [PAPPA]
88INIT_50_80.UNV;1        136  23-FEB-1994 16:03:32.08  [PAPPA]
INIT_0_10.ERA;1             4  20-OCT-1993 15:48:43.04  [PAPPA]
INIT_20_50.ERA;1            4   2-AUG-1993 14:32:14.51  [PAPPA]
INIT_50_80.ERA;1            4  20-OCT-1993 15:49:02.72  [PAPPA]

Total of 21 files, 3101 blocks.
```

3.6 Examining the Tape50 Output File

The "Tape50" output file contains a summary of the ERA results in ASCII format. The actual file name for the Tape50 file is 50*jobname*.LIS, where *jobname* is specified in Field 2 of the ERA User Input file. For the 3 initial analyses of this demonstration problem, the Tape50 files are 50INIT_0_10.LIS, 50INIT_20_50.LIS, and 50INIT_50_80.LIS. Every analysis generates a Tape50 file by default.[107]

[107]That is, ITAPE(50)=1 by default. The Tape50 output file can be deactivated (which is often done in large looping jobs) by including an ITAPE(50)=0 statement in Field 4 of the User Input file. Warning and fatal error messages are still written to Tape50 even when it is "deactivated."

The Tape50 output is 132 columns wide. The author uses a PostScript laser printer for obtaining a hard copy. For example, file 50INIT_0_10.LIS is sent to the PostScript printer by typing

```
LW132 50INIT_0_10.LIS
```

The `LW132` command is available to all ERA users. LW132 is an acronym for "Laser Writer 132 Columns."

The PostScript file is sent to a printer having the logical name PS_OUTPUT_DEVICE. This logical name is defined in the ERA setup file, ERA$:SUERA.COM. Comments in the SUERA.COM file describe how to change the selection of the default printer. (Your system manager has probably already done this for you.) To use a printer other than the default device, simply redefine PS_OUTPUT_DEVICE in your personal LOGIN.COM file after the @[ERA]SUERA command is given. Alternatively, you can place the command in a file named SUERA_USER.COM stored in your login directory. After command procedure SUERA.COM defines all variables for ERA, it searches your login directory for a file named SUERA_USER.COM which is then executed if it is found.

At NASA Langley, PostScript output routes to the laser printer attached to the SDBNY computer (device SDBNY::CSA0:) by typing:

```
PSNY
```

The following message appears on your computer screen showing that PS_OUTPUT_DEVICE has been redefined as device SDBNY::CSA0:

```
$ DEFINE PS_OUTPUT_DEVICE  SDBNY::CSA0:
%DCL-I-SUPERSEDE, previous value of PS_OUTPUT_DEVICE has been superseded
$ SHOW LOGICAL PS_OUTPUT_DEVICE
   "PS_OUTPUT_DEVICE" = "SDBNY::CSA0:" (LNM$PROCESS_TABLE)
$ SET NOVERIFY
```

Similarly, the commands **PSRSM** and **PSDC** redirect PostScript output to printers attached to the SDBRSM and SDBDC computers, respectively. Commands **PSNY**, **PSRSM**, and **PSDC** are defined in the ERA set up file, SUERA.COM. Your system manager can easily modify this file to define other symbols for your convenience. At NASA Langley, the default PostScript printer for ERA output is SDBNY::CSA0:.

The Tape50 file contains 10 sections of data. The various sections are marked on the sample file listed below (file 50INIT_20_50.LIS). A discussion of each section follows the listing. The bold "* Section *" labels do not appear in the Tape50 file.

File 50INIT_20_50.LIS

```
**************
* SECTION 1 *
**************

 * * * ERA -- VERSION 931216 * * *


 LINE 1 FOR COMMENTS
 INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
 FILTERED DATA: 20 - 50 HZ
 USING DEFAULT S.V. CUTOFF
 INIT_20_50:

**************
* SECTION 2 *
**************

TAPE1 FILE NAMES:
----------------
   1. [PAPPA.DEMO]T1_MMST_NAS_SH1_20_50.DAT
   2. [PAPPA.DEMO]T1_MMST_NAS_SH2_20_50.DAT
   3. [PAPPA.DEMO]T1_MMST_NAS_SH3_20_50.DAT

**************
* SECTION 3 *
**************

ANALYSIS PARAMETERS:                                                                                                    DEFAULT
------------------                                                                                                      VALUE
                  (MAX)                                                                                                 -------
 NCH ....... 81 (   81)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                                 MCH
 NRH ....... 520 (  520)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                               MRH
 NIC .......   3 (    3)  - NO. OF INITIAL CONDITIONS (INPUTS)                                                          MIC
 NST ....... 104 (  104)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                                 MST
*NTIM ......  50 ( 1920)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)              -

 SF ........    50.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                             -
*WINDOW ....     0.817    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                                  -
 FMIN ......    20.000    - FMIN OF DATA (FOR "ZOOMED" DATA)                                                        0.0

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                    -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                    -
 IORFIR ....  50           - ORDER OF BANDPASS FIR FILTER                                                            50

 NSFRST ....   1           - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                           1
 NSFLAG() ..               - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]    ALL 1
          1111111111 1111111111 1111111111 1111111111 1111111111 1111111111 1111111111 1111111111 1111111111 1111111111
          1111
*NSTBOT .... 104          - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                     NST

 NGENTH ....   0           - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)  0
*NSTDTA .... 104          - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                              -

 N1 ........   1           - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                           1
 N2 ........   1           - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                               1
 N3 ........   1           - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                               1
 N2LAST ....  10           - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                        10
 N3LAST ....  10           - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                        10

 NSKIP .....   0           - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                   0
 ISTRIP ....   1           - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                   1
 ICAS85 ....   1           - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                            1
 DATABW ....  -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1  -

 MODELC ....   0           - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 MODELD ....   0           - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 NOAD79 ....   0           - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)     0

*RNKTL0 ....  3.14E-05     - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)          SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....-999           - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")                      -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  3.14E-05     - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                              RNKTL0
 2. MXFLAG .   0           - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                   0
 3. POFVAR .  99.9990      - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                           99.999
 4. MXORDR .  60           - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                    0.75 * MIN(NRH,NCH)

 NUMRNK ....   0           -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BY-PASSING CRITERIA 1-4 ABOVE  0

 MIDOPT ....   0           - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]              0

 ITAPE(50) .   1           - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                           1
 ITAPE(51) .   1           - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                               0
 ITAPE(55) .   1           - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                   0
```

```
 ITAPE(79) .    1          - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                                  0
  MXALL ....    0          -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                                    0
  MXHANK ...    0          -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                                 0
  MXPDQT ...    0          -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                                     0
  MXMTM ....    0          -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT                   0
  MXMOMC ...    0          -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                                  0
  MXDATA ...    0          -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                                   0
   MXDNTM ..-999           -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79             MTIM
   MXDNSF ..   1           -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                               1
   MXDNSL .. 104           -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                             NST
   MXDNIF ..   1           -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                               1
   MXDNIL ..   3           -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                             NIC
 ITAPE(80) .   0           - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...   0           - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80                 0
 ITAPE(85) .   1           - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85            1
 ITAPE(88) .   1           - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                               0
 ITYDTA ....   3           - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                             3
 MSSCAL ....   2           - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES            2
 IREFTU ....   0           - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)        0
 T55CMI ....     1.0       - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                           1.0
 T88CMI ....     0.0       - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                           1.0

 MSTO50 ....   0           - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                          0
 MSPP50 ....   1           - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)                    1

 LOOPOP ....   0           - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                       0
  PAR(1) ... -999.00       -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                           -
  PAR(2) ... -999.00       -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                           -
  PAR(3) ... -999.00       -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                           -
  PAR(4) ... -999.00       -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                           -
  PAR(5) ... -999.00       -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                           -
*NCASES ....   1           - NO. OF CONSECUTIVE CASES TO RUN                                                                   1

 IPREMC ....   0           - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                          0
 IPRHRS ....   0           - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH   0
 IPRPDQ ....   0           - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                                   0
 IPRABC ....   0           - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                               0
 IPREVS ....   0           - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                                   0
 IPRDTA ....   0           - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                              0
 IPRPAR ....   0           - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                              0
 MSRTOT ....   0           - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                                   0

 IOMAC .....   0           - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1                   0
 ---------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ---------------------------------------------------------------


 INIT_20_50:

CASE NO.   1:
------------

*************
* SECTION 4 *
*************

D(1) =   3.46692E-03

SINGULAR VALUES, D():                                                                                  CUMULATIVE
                                                                                                          % OF
                                                                                  D(N)/D(1)  D(N)/D(N+1) VARIANCE   N
 1 **************************************************************************************************  1.00E+00    2.182   67.61119   1
 2 ********************************************************************************************      4.58E-01    1.751   81.81516   2
 3 ************************************************************************************              2.62E-01    1.149   86.44823   3
 4 ********************************************************************************                  2.28E-01    1.144   89.95625   4
 5 ****************************************************************************                      1.99E-01    1.256   92.63734   5
 6 ************************************************************************                          1.59E-01    1.049   94.33691   6
 7 ********************************************************************                              1.51E-01    1.241   95.88058   7
 8 ****************************************************************                                  1.22E-01    1.149   96.88246   8
 9 ************************************************************                                      1.06E-01    1.066   97.64114   9
10 ********************************************************                                          9.94E-02    1.066   98.30903   10
11 ****************************************************                                              9.33E-02    1.320   98.89724   11
12 ************************************************                                                  7.07E-02    1.329   99.23493   12
13 ********************************************                                                      5.32E-02    1.189   99.42606   13
14 ****************************************                                                          4.47E-02    1.051   99.56135   14
15 ************************************                                                              4.26E-02    1.047   99.68381   15
16 ********************************                                                                  4.06E-02    1.092   99.79543   16
17 ****************************                                                                      3.72E-02    1.280   99.88905   17
18 ************************                                                                          2.91E-02    1.626   99.94622   18
19 ********************                                                                              1.79E-02    1.149   99.96785   19
20 ****************                                                                                  1.56E-02    1.778   99.98422   20
21 ************                                                                                      8.75E-03    1.155   99.98940   21
22 ********                                                                                          7.58E-03    1.172   99.99329   22
23 ****                                                                                            6.47E-03    1.679   99.99612   23
24 ************************************************                                                  3.85E-03    1.102   99.99712   24
25 ********************************************                                                      3.50E-03    1.297   99.99796   25
26 ****************************************                                                          2.70E-03    1.721   99.99844   26
27 ********************************                                                                1.57E-03    1.059   99.99861   27
28 ****************************                                                                    1.48E-03    1.102   99.99876   28
29 ************************                                                                        1.34E-03    1.185   99.99887   29
30 ********************                                                                            1.13E-03    1.034   99.99895   30
```

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31 ********************************
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72 +++++++++
73 +++++++++
74 ++++++++
75 +++++++
76 +++++
77 +++
78 +++
79 ++
80 +
81 +
```

1.10E-03	1.032	99.99904*	31
1.06E-03	1.062	99.99911	32
1.00E-03	1.025	99.99918	33
9.76E-04	1.032	99.99924	34
9.46E-04	1.034	99.99931	35
9.15E-04	1.024	99.99937	36
8.93E-04	1.002	99.99941	37
8.91E-04	1.042	99.99947	38
8.55E-04	1.007	99.99952	39
8.49E-04	1.033	99.99957	40
8.22E-04	1.023	99.99961	41
8.04E-04	1.033	99.99966	42
7.78E-04	1.002	99.99969	43
7.77E-04	1.034	99.99973	44
7.52E-04	1.030	99.99977	45
7.30E-04	1.045	99.99982	46
6.98E-04	1.018	99.99985	47
6.85E-04	1.156	99.99988	48
5.93E-04	1.125	99.99990	49
5.27E-04	1.100	99.99992	50
4.79E-04	1.042	99.99994	51
4.60E-04	1.185	99.99995	52
3.88E-04	1.261	99.99996	53
3.08E-04	1.046	99.99997	54
2.94E-04	1.014	99.99998	55
2.90E-04	1.052	99.99998	56
2.76E-04	1.053	100.00000	57
2.62E-04	1.017	100.00000	58
2.58E-04	1.023	100.00000	59
2.52E-04	1.017	100.00000	60
2.48E-04	1.028	100.00000	61
2.41E-04	1.039	100.00000	62
2.32E-04	1.033	100.00000	63
2.25E-04	1.029	100.00000	64
2.18E-04	1.181	100.00000	65
1.85E-04	1.332	100.00000	66
1.39E-04	1.054	100.00000	67
1.32E-04	1.044	100.00000	68
1.26E-04	1.036	100.00000	69
1.22E-04	1.083	100.00000	70
1.12E-04	1.067	100.00000	71
1.05E-04	1.184	100.00000	72
8.90E-05	1.078	100.00000	73
8.25E-05	1.079	100.00000	74
7.64E-05	1.382	100.00000	75
5.53E-05	1.224	100.00000	76
4.52E-05	1.037	100.00000	77
4.36E-05	1.036	100.00000	78
4.20E-05	1.122	100.00000	79
3.75E-05	1.099	100.00000	80
3.41E-05		100.00000	81

* SINGULAR VALUE TRUNCATION OCCURRED AT ORDER = 31 *

****
* SECTION 5 *
****

INPUT (REFERENCE) COORDINATE CODES:

IC NO.	COORDINATE CODE	MEAS. NO.
1	201Z+	103
2	23Y+	74
3	203Z+	104

****
* SECTION 6 *
****

* NOTE: FMIN = 20.0000, SF = 60.0000, N1 = 1, ISTRIP = 1.

THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN 20.0000 & 50.0000 HZ

****
* SECTION 7 *
****

IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):

	E.V. NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (3)	OUTPUT (104)		MPC-W	MPC-U	PRC		ARATIO		RECIP-PROCITY	MSR,%
1	6	30.717**	0.992	(0.990)	:	97.35**	97.35	: 3	102	:	100.00	99.23	998	:	0.217	:	100.0	28.7
2	7	32.069**	1.002	(1.005)	:	96.29**	96.29	: 3	104	:	100.00	99.97	999	:	0.198	:	100.0	20.6
3	10	42.227**	1.003	(0.998)	:	95.17**	95.17	: 3	100	:	100.00	99.80	997	:	0.120	:	100.0	11.9

4	3	21.571*	0.906	(0.930)	93.67*	93.67	3	84	100.00	79.21	998	0.365	100.0	91.0
5	9	39.005*	1.022	(1.022)	92.52*	92.58	2	81	99.93	91.13	991	0.135	99.1	5.1
6	11	44.860*	0.971	(0.989)	92.47*	92.48	3	100	100.00	99.21	999	0.107	100.0	14.5
7	5	28.628	1.109	(1.018)	74.14	74.18	1	92	99.94	94.80	992	0.231	99.8	5.7
8	4	23.536	1.168	(0.992)	57.14	57.23	0	69	99.84	89.30	987	0.309	99.4	11.0
9	8	36.908	3.482	(1.504)	0.01	0.01	0	0	67.01	15.55	783	0.061	69.9	0.5
10	2	20.303	48.674	(6.241)	0.00	0.00	0	0	35.37	7.53	634	0.002	53.6	5.8
11	12	49.701	34.119	(1.990)	0.00	0.00	0	0	98.30	76.57	957	0.007	71.9	6.6
12	1	20.013	8.078	(4.466)	0.00	0.00	0	13	76.01	31.55	864	0.011	22.1	6.9

****
* SECTION 8 *
****

IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):

E.V. NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (3)	OUTPUT (104)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	7	32.069**	1.002	(1.005)	96.29**	96.29	3	104	100.00	99.97	999	0.198	100.0	20.6
2	3	21.571*	0.906	(0.930)	93.67*	93.67	3	84	100.00	79.21	998	0.365	100.0	91.0
3	11	44.860*	0.971	(0.989)	92.47*	92.48	3	100	100.00	99.21	999	0.107	100.0	14.5
4	6	30.717**	0.992	(0.990)	97.35**	97.35	3	102	100.00	99.23	998	0.217	100.0	28.7
5	10	42.227**	1.003	(0.998)	95.17**	95.17	3	100	100.00	99.80	997	0.120	100.0	11.9
6	5	28.628	1.109	(1.018)	74.14	74.18	1	92	99.94	94.80	992	0.231	99.8	5.7
7	9	39.005*	1.022	(1.022)	92.52*	92.58	2	81	99.93	91.13	991	0.135	99.1	5.1
8	4	23.536	1.168	(0.992)	57.14	57.23	0	69	99.84	89.30	987	0.309	99.4	11.0
9	12	49.701	34.119	(1.990)	0.00	0.00	0	0	98.30	76.57	957	0.007	71.9	6.6
10	1	20.013	8.078	(4.466)	0.00	0.00	0	13	76.01	31.55	864	0.011	22.1	6.9
11	8	36.908	3.482	(1.504)	0.01	0.01	0	0	67.01	15.55	783	0.061	69.9	0.5
12	2	20.303	48.674	(6.241)	0.00	0.00	0	0	35.37	7.53	634	0.002	53.6	5.8

****
* SECTION 9 *
****

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

E.V. NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (3)	OUTPUT (104)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	20.013	8.078	(4.466)	0.00	0.00	0	13	76.01	31.55	864	0.011	22.1	6.9
2	2	20.303	48.674	(6.241)	0.00	0.00	0	0	35.37	7.53	634	0.002	53.6	5.8
3	3	21.571*	0.906	(0.930)	93.67*	93.67	3	84	100.00	79.21	998	0.365	100.0	91.0
4	4	23.536	1.168	(0.992)	57.14	57.23	0	69	99.84	89.30	987	0.309	99.4	11.0
5	5	28.628	1.109	(1.018)	74.14	74.18	1	92	99.94	94.80	992	0.231	99.8	5.7
6	6	30.717**	0.992	(0.990)	97.35**	97.35	3	102	100.00	99.23	998	0.217	100.0	28.7
7	7	32.069**	1.002	(1.005)	96.29**	96.29	3	104	100.00	99.97	999	0.198	100.0	20.6
8	8	36.908	3.482	(1.504)	0.01	0.01	0	0	67.01	15.55	783	0.061	69.9	0.5
9	9	39.005*	1.022	(1.022)	92.52*	92.58	2	81	99.93	91.13	991	0.135	99.1	5.1
10	10	42.227**	1.003	(0.998)	95.17**	95.17	3	100	100.00	99.80	997	0.120	100.0	11.9
11	11	44.860*	0.971	(0.989)	92.47*	92.48	3	100	100.00	99.21	999	0.107	100.0	14.5
12	12	49.701	34.119	(1.990)	0.00	0.00	0	0	98.30	76.57	957	0.007	71.9	6.6

****
* SECTION 10 *

```
**************
VAX EXECUTION STATISTICS:
-------------------------
COMPUTER NODENAME AND TYPE:  SDBHR,  VAXstation 3100-M76/GPX
ELAPSED:     0 00:01:26.74  CPU: 0:00:57.29  BUFIO: 172  DIRIO: 739  FAULTS: 1837
START DATE/TIME:  23-FEB-1994 15:55
  END DATE/TIME:  23-FEB-1994 15:56
```

Section 1 of the Tape50 file shows the current version number of the software (YYMMDD) and the five lines of comments from Field 5 of the User Input file.

Section 2 lists the names of the Tape1 data files. Response data for each input (initial condition) is contained in a separate file. See Section 4.1 for a description of the Tape1 data format.

Section 3 lists all available analysis parameters and their default values. This information appears at the beginning of every Tape50 file.

All parameters in this list except those preceded by an asterisk can be specified in the NAMELIST section (Field 4) of the User Input file. Parameters with asterisks are computed internally by the software and cannot be specified by the user. They are printed here for information only. Only a few analysis parameters are typically changed from their default values in each job. **All analysis parameters not appearing in Field 4 of the User Input file retain their default values.**

The first 4 parameters (NCH, NRH, NIC, and NST) are not normally specified by the user. By default, these values equal parameters MCH, MRH, MIC, and MST, respectively, specified in Field 3 of the User Input file. MCH, MRH, MIC, and MST are dimensions of various FORTRAN arrays. They are acronyms for the maximum value that the corresponding "N" parameter can have. To select an "N" parameter value different than the corresponding "M" parameter, include it in the NAMELIST section (Field 4) of the User Input file provided is no larger than the corresponding "M" parameter. On the Tape50 listing, the numbers appearing in parentheses to the right of NCH, NRH, NIC, NST, and NTIM are MCH, MRH, MIC, MST, and MTIM. MTIM, the total number of time samples in each Tape1 data record, is also specified in Field 3 of the User Input file. NTIM, the actual number of time samples used in the analysis, is computed internally by the software.

Chapter 6 describes the remaining analysis parameters.

Section 4 of the Tape50 file is a logarithmic printer plot and listing of the singular values of the generalized Hankel matrix arranged in decreasing order of magnitude. Horizontal lines of asterisks indicate retained singular values while horizontal lines of plus signs indicate truncated singular values. This demonstration problem retains 31 singular values. In some analyses, a blank line followed by a line of X's may also appear. Singular values

beginning at the X's are smaller than a calculated threshold corresponding to the numerical rank of the matrix.[108] The line of X's normally does not appear with experimental data because noise and other data distortions cause the Hankel matrix to be of full numerical rank. The maximum number of singular values that can be retained equals the number of non-zero singular values. In this demonstration problem, all 81 singular values are non-zero.

The singular values are tabulated 3 different ways to the right of the plot. The first column lists the magnitude of each singular value, D(N), divided by the largest singular value, D(1). This information can be used to judge the point at which the singular values become "small enough."[109] The second column lists the ratio of consecutive singular values, D(N)/D(N+1). A large number in this column (e.g., greater than 20) at singular value N indicates that the data can be closely approximated by an Nth-order model (N/2 modes). With most data sets, no large value whatsoever occurs in this column (all values are typically less than 2.0) indicating ambiguity in the number of modes present.[110] The third column lists the cumulative percentage of variance (CPV), computed as the running sum of squares of the singular values divided by the total sum of squares of the singular values. By definition of the singular value decomposition, the sum of squares of all singular values equals the sum of squares of all elements of the Hankel matrix. If an estimate of the signal-to-noise ratio of the data is available, this information establishes the point at which the singular values become dominated by noise. Noise dominates the singular values at the following CPV levels for the indicated noise levels:[111]

% NOISE	SNR, dB	CPV, %
31.6	10	90.
10.0	20	99.
3.16	30	99.9
1.0	40	99.99
0.316	50	99.999
0.1	60	99.9999
0.0316	70	99.99999
0.01	80	99.999999

[108]Numerical rank is the rank of the matrix based on the numerical resolution of the SVD computation. It corresponds to a rank tolerance of RNKTL0 = SQRT(NRH*NRH + NCH*NCH) * EPS, where EPS is the machine precision (Ref. 20).

[109]Non-zero values of D(N)/D(1) can be no smaller than approximately 1e-7 because the Tape1 data are stored as single-precision words.

[110]This ambiguity occurs in practice because of a wide spread of signal-to-noise ratios of the modes, and in the case of IRF data derived by inverse Fourier transformation of FRFs, because of the truncation of modes at the frequency limits of the analysis (see Section 3.4 and Fig. 3-4).

[111]Signal-to-noise ratio, SNR = RMS signal / RMS noise over the data analysis window.

Table 3-1. Relationship of Percent Noise, SNR, and CPV

The relationship between % Noise and SNR in dB is:

$$SNR = -20 \cdot \log_{10}(\frac{\%\ NOISE}{100}) \tag{3-2}$$

The relationship between SNR in dB and CPV in % is:

$$CPV = (1 - 10^{\frac{-SNR}{10}}) \cdot 100 \tag{3-3}$$

The ERA software truncates singular values at the smallest value among 4 criteria. These criteria correspond to the 4 columns of information on the righthand side of the singular value printer plot (D(N)/D(1), D(N)/D(N+1), CPV, and N). The criterion responsible for the selected truncation value is indicated by an asterisk adjacent to the corresponding value. For example, an asterisk appears in the third column adjacent to the number 99.9904 at the 31st singular value in this demonstration problem. This indicates that the third truncation criterion (i.e., a particular value of CPV) was responsible for the selected truncation point. Truncation occurred when CPV became greater than POFVAR = 99.999 (the default value).[112]

You can always specify a particular singular value cutoff if you wish. This is done using analysis parameter IORDTU, which is an acronym for "order to use." Specifying IORDTU=n in Field 4 of the User Input file causes exactly n singular values to be retained. All other singular-value truncation logic is disabled. *Note that m "assumed modes" requires 2m retained singular values (IORDTU = 2m) because each mode corresponds to a complex-conjugate pair of eigenvalues.*

The singular value truncation point is also printed on Tape50 at the end of Section 4. If a line of X's appeared in the printer plot, the corresponding numerical rank is also given.

Singular values can also be plotted with DIGLIB using program ERAG3. The singular values are read from the Tape85 output file. A demonstration GO Input file named G3_DEMO.COM is available in directory ERA$GO for this purpose. **Fig. 3-5** shows the resulting plot. Shading highlights the 31 retained singular values.

[112]The default value of POFVAR = 99.999 was selected empirically by the author based on many experimental data sets.

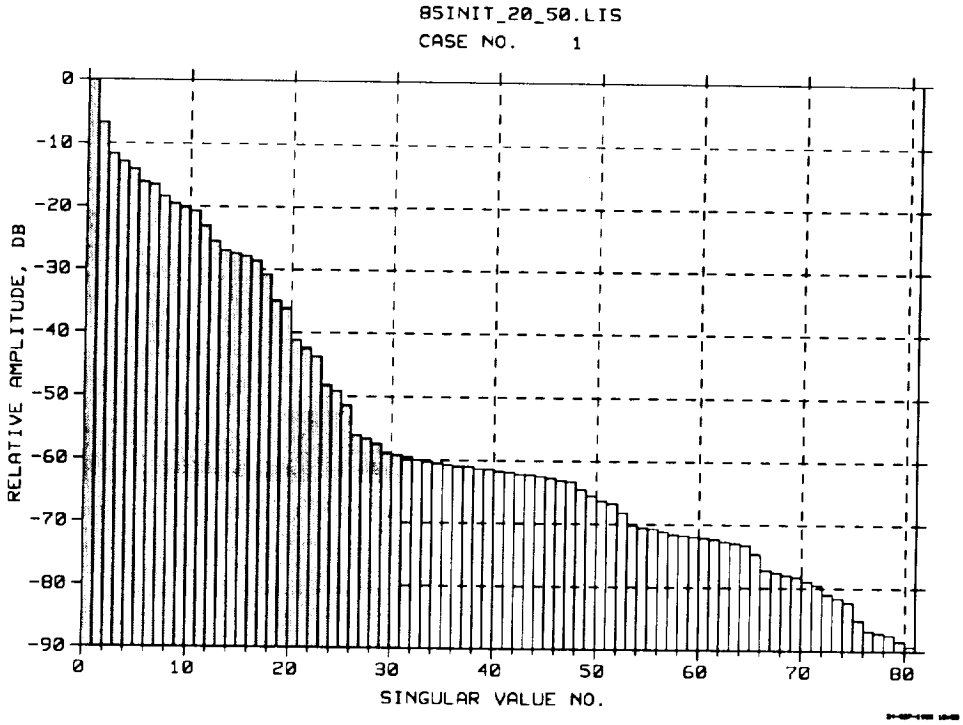


Fig. 3-5. Singular Values of Job INIT_20_50 [G3_DEMO]

Section 5 lists the coordinate codes of the inputs (extracted from columns 2 and 3 of the Coordinate-Code files) and the corresponding response measurement number of the driving point for this input. A warning message occurs if no driving-point measurement exists.

Section 6 lists the values of parameters FMIN, SF, N1, and ISTRIP, and the corresponding frequency range in which all identified modes are assumed to exist. If N1 is greater than 1, the identified frequencies can "alias" to incorrect values due to the discrete nature of the data.[113] If aliasing occurs, the computed damping factors are also wrong. In some situations, users may purposely elect to alias the results to improve identification of closely spaced or low-frequency modes. A preferred approach, however, is to use digital filtering, e.g., program ERAP20. If N1 = N (N > 1) and analysis parameter IPREVS = 1, frequency and damping values are printed on Tape50 for N1 = N, N-1, ... 1.

Section 7 summarizes the identification results sorted by Consistent-Mode Indicator, CMI (Ref. 8).[114] CMI is the primary ERA accuracy indicator, although other indicators are also

[113]The transformation of discrete eigenvalues (z) to continuous eigenvalues (s) is non-unique, $s = \ln z/\Delta t$, where $\Delta t = N1/SF$. All identified eigenvalues are assumed to lie between 0 and $SF/(2 \cdot N1)$ Hz (primary strip).

[114]Only 8 of the 13 frequencies in the 20-50 Hz interval are identified (list of NASTRAN frequencies given in Section 15.13). This is consistent with the number of peaks in the APS and MIF functions, Fig. 3-6. The other modes are very weakly excited and are below the noise floor.

considered (see Section 2.5). Modes with CMI values greater than approximately 80 percent are identified with high confidence. Modes with values ranging from approximately 80 to 1 percent display moderate to large uncertainty. Fictitious "computational modes" have CMI values of approximately zero.

Identification results appear in 15 columns as follows:

Column 1 is a simple index increasing from 1 to NCMDS, the number of complex modes (i.e., the number of identified complex-conjugate pairs of eigenvalues). NCMDS*2 + NREVAL = IORDER, where NREVAL = No. of identified real eigenvalues and IORDER = No. of retained singular values.

Column 2 is the "Eigenvalue Number." This terminology is used (rather than "Mode Number") because a fraction of the results may be "computational (fictitious) modes" rather than true structural modes. In this demonstration problem, there are 4 computational modes (Eigenvalue Nos. 1, 2, 8, and 12). Eigenvalue Numbers increase in order of increasing frequency.

Column 3 is the identified **damped** natural frequency in Hertz.[115] Modes with CMI values of at least 95 percent are highlighted with 2 asterisks. Modes with CMI values between 95 and 90 percent are highlighted with 1 asterisk. Modes with CMI values between 90 and 80 percent are highlighted with a plus sign. These asterisks and plus signs also appear adjacent to the corresponding CMI values.

Column 4 is the identified damping factor (fraction of critical damping) calculated from the identified s-plane eigenvalue as follows:

$$\zeta = -\frac{\sigma}{\sqrt{\sigma^2 + \omega_d^2}} \, x \, 100\% \tag{3-4}$$

where σ = real part of s-plane eigenvalue
ω_d = imaginary part of s-plane eigenvalue

Column 5 is a second damping factor estimate referred to as ζ_2 ("zeta2"). It is computed using the identified eigenvector (mode shape) components for data at the beginning and end of the analysis time window, and the corresponding identified damped natural frequency, as follows:

$$\zeta_2 = -\frac{\sigma_2}{\omega_{n2}} \, x \, 100\% \tag{3-5}$$

where

[115] All ERA-associated frequencies are **damped** natural frequencies, unless otherwise noted.

$$\sigma_2 = \frac{\ln(A_e/A_b)}{T} \tag{3-6}$$

$$\omega_{n2} = \sqrt{\sigma_2^{\,2} + \omega_d^{\,2}} \tag{3-7}$$

A_b = Maximum identified mode-shape component at beginning of analysis window
A_e = Corresponding identified mode-shape component at end of analysis window
T = Duration of analysis window (sec)
ω_d = Identified damped natural frequency (rad/sec)

Theoretically, ζ_2 (column 5) should equal the damping factor calculated from the identified s-plane eigenvalue, ζ (column 4). In practice, however, differences occur. The magnitude of the difference provides a reliability estimate for the damping results. No general trend concerning the relative accuracy of ζ vs ζ_2 is known. (In this demonstration problem, Job INIT20_50, ζ_2 is more accurate than ζ for 5 of 8 identified modes.)

Column 6 is the Consistent Mode Indicator (CMI) in percent (Ref. 8). CMI is the primary ERA accuracy indicator. Values greater than approximately 80% designate well-identified structural modes. CMI values of at least 95 percent are highlighted with 2 asterisks. Values between 95 and 90 percent are highlighted with 1 asterisk. Values between 90 and 80 percent are highlighted with a plus sign. CMI is the product of the Average Extended Modal Amplitude Coherence, EMAC (column 7) and the Weighted Modal Phase Collinearity, MPC-W (column 10).

Column 7 is the Average Extended Modal Amplitude Coherence (EMAC) in percent (Ref. 8). It quantifies the temporal consistency of the identification results on a mode-by-mode basis and is used in calculating CMI. (CMI = EMAC x MPC-W).

Column 8 lists the number of inputs (initial conditions) that have EMAC values greater than 80 percent. The total number of inputs used in the analysis appears in parentheses at the top of the column.

Column 9 lists the number of outputs (response measurements) that have EMAC values greater than 80 percent. The total number of outputs used in the analysis appears in parentheses at the top of the column.

Column 10 is the Weighted Modal Phase Collinearity (MPC-W) in percent (Ref. 8). It quantifies the spatial consistency of the identification results on a mode-by-mode basis and is used in calculating CMI. (CMI = EMAC x MPC-W). Modes with monophase behavior have MPC-W values of 1.0.

Column 11 is the Unweighted Modal Phase Collinearity (MPC-U) in percent. A large difference between the MPC-W and MPC-U values indicates local response behavior (i.e., significant motion at only a few measurement locations) (Ref. 8).

Column 12 is the Phase Resonance Criterion, PRC (Refs. 10,11). PRC values range from 0 to 1000. Modes with monophase behavior have PRC values of 1000. This accuracy indicator is similar to MPC-W.

Column 13 is "ARATIO," an abbreviation for "Amplitude Ratio," defined as follows:

$$\alpha = \frac{A_e}{A_b} \tag{3-8}$$

where

A_b = Maximum identified mode shape component at beginning of analysis window
A_e = Corresponding identified mode shape component at end of analysis window

ARATIO helps estimate the suitability of the data-analysis window length (NTIM data samples). A small ARATIO value (e.g., less than 0.05) indicates that the data near the end of the window is probably affected significantly by noise, particularly if the Modal Strength Ratio (Column 15), is small (e.g., less than 1.0). Under these conditions, the identification accuracy of this mode would probably improve using a shorter window length. With a large ARATIO value (e.g., greater than 0.50), on the other hand, the identification accuracy of this mode would probably improve using a longer window length.

The calculation of Zeta2 (column 5 defined above) uses ARATIO.

Column 14 is a reciprocity check which is an excellent accuracy indicator when impulse response function (FRF) data are used in the analysis. (The results are meaningless with arbitrary free-decay data). Reciprocity is the square of the correlation coefficient of the vector of identified modal participation factors at each available driving point and the vector of identified mode shapes at the same set of points, defined as follows:

$$\rho = \frac{\left|\chi^H \phi\right|^2}{(\chi^H \chi)(\phi^H \phi)} \, x \, 100\% \tag{3-9}$$

where

χ = Vector of identified modal participation factors at the available driving points
ϕ = Vector of identified mode shapes at the available driving points

Perfect reciprocity corresponds to a ρ value of 100%. Good reciprocity corresponds to ρ values greater than approximately 90%. Poor reciprocity corresponds to ρ values less than approximately 50%.

If NIC = 1 (only 1 input is available), -999.0 appears in column 14 indicating a meaningless result (calculation of a valid correlation coefficient requires at least 2 data points in each vector).

Column 15 is the Modal Strength Ratio (MSR). MSR is the root-mean-square (rms) value of the identified modal response divided by the rms value of all elements of the Hankel matrix. A small MSR value (e.g., less than 1.0) indicates that this particular mode was not strongly excited (and/or measured). The square root of the sum of the squares of all MSR values equals (approximately) 100%.[116]

Warning: Inaccurate MSR values (e.g., > 100 %) may occur when only a small number of cycles of data (e.g., less than 3) are included in the data-analysis time window.

Section 8 is identical to Section 7 except the results are sorted by Weighted Modal Phase Collinearity (MPC-W).

Section 9 is identical to Section 7 except the results are sorted by the identified (damped natural) frequency.

Section 10 provides various execution statistics such as elapsed time and CPU usage.

3.7 Comparison of Identified Frequencies With Spectral Peaks (ERAG7)

The ERA-identified natural frequencies can be compared with peaks in data spectra using post-processor program ERAG7. ERAG7 is identical to ERAG1 except it plots only frequency-domain data and then highlights frequencies corresponding to the ERA results. ERA-identified natural frequencies are read from a specified Tape85 file.

You can plot any record(s) from a Tape1 data file. Often, the average power spectrum (APS) and mode indicator function (MIF) generated by program ERAG4 are plotted because they provide a good overview of a complete data set. You can save the computed APS and MIF functions in Tape1 format when ERAG4 is run.

If you have executed file G4_DEMO.COM as described in Section 12.12, a Tape1 file named T1APS_MIF_DEMO.DAT containing the APS and MIF for this demonstration problem exists in your working directory. If you have not already done this, a copy of the

[116]The square root of the sum of the squares of all MSR values is printed on Tape50 by specifying MSRTOT=1 in Field 4 of the User Input file.

file is available in directory ERA$MMST_NAS which you should now copy to your working directory.

Also copy files G7_OPTIONS_DEMO.DAT and FREQS_AND_DAMPS.DAT into your working directory as follows:

```
COPY ERA$OPTIONS:G7_OPTIONS_DEMO.DAT G7_OPTIONS.DAT

COPY ERA$MMST_NAS:FREQS_AND_DAMPS.DAT []
```

File G7_OPTIONS_DEMO.DAT activates the MARKFD=1 hidden option (ref. Section 8.3) that plots triangles at the top of the figure at the frequencies of NASTRAN modes. MARKFD is an acronym for "mark frequency and damping values." With program ERAG7, only frequencies are marked.[117] Note that G7_OPTIONS_DEMO.DAT is renamed to G7_OPTIONS.DAT when it is copied. Here are the contents of this file:

```
$G7_OPTIONS
MARKFD=1,TFDNAM='FREQS_AND_DAMPS.DAT'
$END
```

File FREQS_AND_DAMPS.DAT is an ASCII file containing the NASTRAN frequencies (Hz) and assumed damping factors (%). Here are the first 10 lines of the file. The complete file contains data for all 153 NASTRAN modes (ref. Section 12.13).

```
 1      0.7982200      2.0000000
 2      0.7995700      2.0000000
 3      4.3687000      1.5000000
 4      6.1062002      1.0000000
 5      6.1594000      1.0000000
 6     14.6149998      1.0000000
 7     14.8149996      1.0000000
 8     14.9619999      1.0000000
 9     15.5679998      1.0000000
10     15.6000004      1.0000000
```

Now, copy and execute GO Input file G7_DEMO.COM as follows:

```
COPY ERA$GO:G7_DEMO.COM []

GO G7_DEMO
```

Fig. 3-6 shows the resulting plot.

[117]The MARKFD=1 hidden option is also available with post-processor ERAG15. With ERAG15, both frequencies and damping results can be marked.

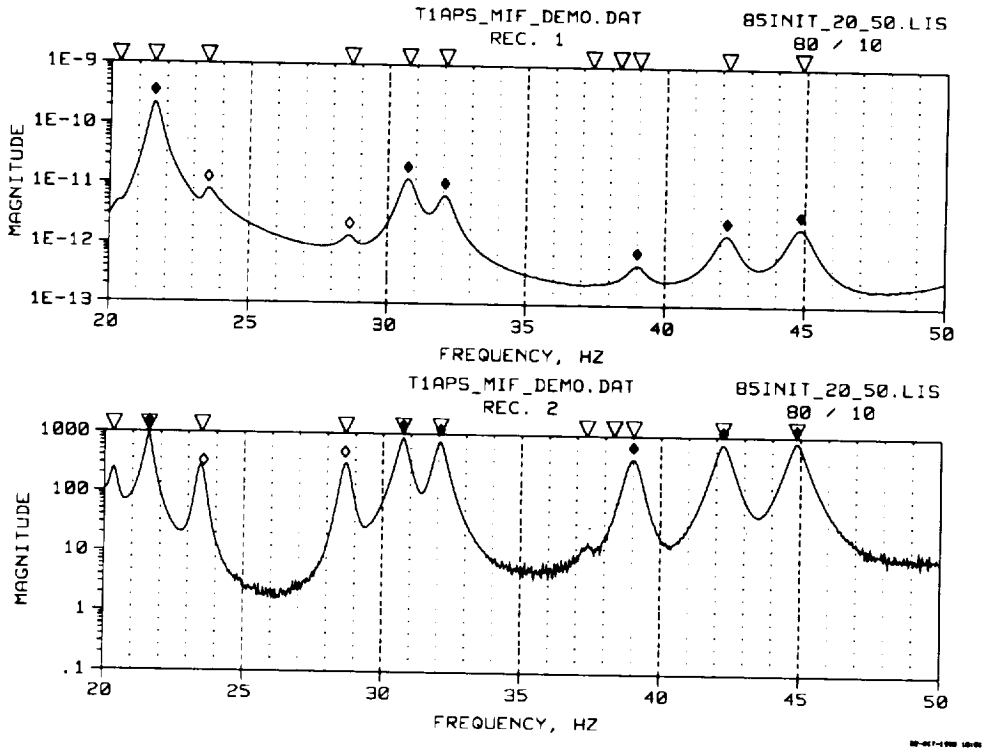


Fig. 3-6. Identified Natural Frequencies (Job INIT_20_50) Superimposed on APS and MIF Functions [G7_DEMO]

The ERA-identified frequencies read from file 85INIT_20_50.LIS are marked on both the APS (top) and MIF (bottom) functions using diamonds. Darkened and open diamonds indicate the relative quality of the identification results. In this example, darkened symbols correspond to modes with CMI values (Ref. 8) of at least 80 percent. Open symbols correspond to modes with CMI values between 80 and 10 percent. Modes with CMI values less than 10 percent are skipped. These two CMI thresholds (80% and 10%) are documented at the upper right of the plot below the Tape85 file name. Both thresholds are user-specified values. The name of the Tape1 file and the data record numbers also appear.

Note that the mode indicator function (bottom figure) uses a logarithmic magnitude scale rather than the traditional linear scale. You can select either logarithmic or linear magnitude scales when running program ERAG7 (or ERAG1). However, the selection applies to all functions plotted in the same run. You can replot Fig. 3-6 with linear magnitude scales using GO input file ERA$GO:G7_LINEARMAG_DEMO.COM.

Here is a listing of file G7_DEMO.COM:

```
$! G7_DEMO.COM
$!
$ RUN ERA$EXES:ERAG7
T1APS_MIF_DEMO      TAPE1 FILENAME
```

```
1             FIRST RECORD TO PLOT
2             LAST RECORD TO PLOT
1             RECORD INCREMENT BETWEEN PLOTS
1             NO. OF PLOTS TO PLACE HORIZONTALLY ON PAGE
2             NO. OF PLOTS TO PLACE VERTICALLY ON PAGE
1             NO. OF CONSECUTIVE FUNCTIONS TO OVERLAY IN EACH PLOT
1             LINE STYLE?  1=SOLID, 2=SOLID & 3 DASHED (CYCLICALLY), 3=SOLID LINE...
1             LINEAR(0) OR LOG(1) SPECTRUM MAGNITUDE PLOT?
4             NO. OF DECADES TO USE ON FREQ. PLOT
0             VALUE FOR Y-AXIS MAX.  0=AUTOSCALE
0             HIGHLIGHT EACH PT. ON SPECTRUM WITH A SYMBOL?  1=YES
0             INCLUDE COORDINATE CODES?  1=YES
160           SAMPLING FREQ., HZ
0             DATA FMIN
              NO. OF POINTS TO FOURIER TRANSFORM (DEFAULT = ALL)
0             USE HANNING WINDOW?  1=YES
0             REMOVE DC VALUE?  1=YES
20            FMIN TO PLOT (DEFAULT = DATA FMIN)
50            FMAX TO PLOT (DEFAULT = SF/2 + DATA FMIN)
1             DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS
0.0           FREQ. FOR FIRST X-AXIS MINOR TIC MARK.  0.0 = ORIGIN OF PLOT
0             PLOT ABS(IMAG. PART) RATHER THAN MODULUS?  1=YES
1             SKIP SPECTRUM PHASE PLOT?  1=YES
1             INCLUDE X-AXIS GRID LINES ON FREQ. PLOT?  1=YES
1             ADD ADDITIONAL DOTTED VERTICAL LINES AT MINOR TICS?  1=YES
0.3           CHARACTER SIZE IN CM
1             FONT TYPE.  1=STICK
0             PRINT OUT SPECTRUM TO FILE G1_SPECTRUM.OUT?  1=YES
85INIT_20_50   TAPE85 FILE
1             CASE NO. TO USE FROM TAPE85
80            MINIMUM CMI FOR DARKENED SYMBOLS
10            MINIMUM CMI FOR   OPEN   SYMBOLS
1.0           SYMBOL SIZE, AS A FRACTION OF CHARACTER SIZE
1             USE DEFAULT OVERALL WINDOW SIZE?  1=YES
0             MODIFY DEFAULT AXIS NUMBERS?  1=YES
```

The following information appears on your computer screen when G7_DEMO is run:

```
ERAG7.  PLOT IDENTIFIED FREQS. (FROM TAPE85) ON AN ERAG1-TYPE FREQ. PLOT

TAPE1 FILENAME ? [DEFAULT FILE TYPE = .DAT]
T1APS_MIF_DEMO.DAT

FIRST RECORD NO. TO PLOT ?  (1)
          1

LAST RECORD NO. TO PLOT ?  (1)
          2

RECORD INCREMENT BETWEEN PLOTS ?  (1)
          1

NO. OF PLOTS TO PLACE HORIZONTALLY ON THE PAGE ?  (2)
```

```
          1

NO. OF PLOTS TO PLACE VERTICALLY ON THE PAGE ?  (2)
          2

NO. OF CONSECUTIVE FUNCTIONS TO OVERLAY IN EACH PLOT ?  (1)
          1

LINE STYLE ?  (1)
 1 = SOLID LINES
 2 = 4 ALTERNATING LINE TYPES: SOLID & 3 TYPES OF DASHED LINES
 3 = SOLID ON LINE #1 ONLY; THEN 3 TYPES OF ALTERNATING DASHED LINES
          1

LINEAR(0) OR LOG(1) AXIS FOR SPECTRUM MAGNITUDE ?  (1)
          1

NO. OF DECADES TO SHOW ON SPECTRUM MAGNITUDE PLOT ?  (4)
          4

VALUE TO USE FOR Y-AXIS MAX. ON SPECTRUM MAGNITUDE PLOT ? 0=AUTOSCALE  (0)
 0.0000000E+00

HIGHLIGHT EACH DATA PT. ON SPECTRUM WITH A SYMBOL ?  1=YES.  (0)
          0

INCLUDE COORDINATE CODES ON PLOT ?  1=YES.  (1)
          0

ENTER SF [SAMPLING FREQUENCY IN HERTZ] ?  (100.)
  160.0000

DATA FMIN ? [> 0 FOR ZOOMED DATA]  (0.)
 0.0000000E+00

   5120 TOTAL AVAILABLE TIME SAMPLES =   31.994 SECONDS

ENTER NO. OF TIME SAMPLES TO FOURIER TRANSFORM ?  (  5120)
[ANY VALUE PERMITTED; SUBROUTINE SFT IS NOT RESTRICTED TO ONLY POWERS-OF-2]
       5120

USE HANNING WINDOW ? 1=YES.  (0)
          0

REMOVE DC VALUE ?  1=YES.  (0)
          0

FMIN TO PLOT ?  (  0.000)
  20.00000

FMAX TO PLOT ? (   80.000)
  50.00000

DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS ? 0=NONE  (1.0)
```

```
  1.000000

FREQ. OF FIRST X-AXIS MINOR TIC MARK ?  0.0 = ORIGIN OF PLOT. (0.0)
 0.0000000E+00

PLOT ABS(IMAG. PART) RATHER THAN MODULUS ?  1=YES.  (0)
          0

SKIP SPECTRUM PHASE PLOT ?  1=YES  (0)
          1

INCLUDE X-AXIS GRID LINES ON FREQ-DOMAIN PLOT
(AT EACH MAJOR TIC) ?  1=YES  (1)
          1

ALSO ADD ADDITIONAL DOTTED VERTICAL LINES AT MINOR TIC MARKS ?  1=YES.  (1)
          1

CHARACTER SIZE (HT.) FOR PLOT LABELS, IN CM ?  (0.3)
 0.3000000

FONT TYPE ?  (1)
 1 = STICK FONT
 2 = LETTER QUALITY - BOLD
 3 = LETTER QUALITY - STD.
          1

PRINT OUT SPECTRUM TO FILE G1_SPECTRUM.OUT ?  1=YES  (0)
          0

IDENTIFIED FREQUENCIES FROM TAPE85 WILL BE PLOTTED AS DIAMONDS
ABOVE THE FREQ-DOMAIN AMPLITUDE PLOT.

TAPE85 FILENAME ?  [DEFAULT FILE TYPE = .LIS])
85INIT_20_50.LIS

CASE NO. TO USE FROM TAPE85?  (1)
          1

MINIMUM CMI FOR DARKENED SYMBOLS ?  (70.)
(OTHER MODES WILL BE MARKED WITH OPEN SYMBOLS)
  80.00000

MINIMUM CMI FOR OPEN SYMBOLS ?  (30.)
  10.00000

DIAMOND SIZE, AS A FRACTION OF CHARACTER SIZE ?  (1.0)
  1.000000
EIGENVALUE NO., FD, CMI =     3     21.57     93.67
EIGENVALUE NO., FD, CMI =     4     23.54     57.14
EIGENVALUE NO., FD, CMI =     5     28.63     74.13
EIGENVALUE NO., FD, CMI =     6     30.72     97.35
EIGENVALUE NO., FD, CMI =     7     32.07     96.29
EIGENVALUE NO., FD, CMI =     9     39.01     92.52
```

```
EIGENVALUE NO., FD, CMI =    10     42.23     95.17
EIGENVALUE NO., FD, CMI =    11     44.86     92.48

USE THE DEFAULT OVERALL WINDOW SIZE ? 1=YES  (1)
          1

MODIFY DEFAULT AXIS NUMBERS ?  1=YES  (0)
          0

GRAPHICS DEVICE NUMBER ?  (4)
  1 = TEK. 4010
  2 = TEK. 4014
  3 = TEK. 4025
  4 = TEK. 4107
  5 = TEK. 4115B
  6 = HP 2647/2648
  7 = DEC VT240
  8 = HPGL TALL
  9 = HPGL WIDE
 10 = POSTSCRIPT TALL
 11 = POSTSCRIPT WIDE
```

3.8 MAC and/or Orthogonality Calculations (ERAP25 & ERAG25)

Program ERAP25 calculates Modal Assurance Criteria (MAC) or orthogonality between mode shapes. A temporary disk file holds the results which can then be plotted with program ERAG25. ERAP25 reads mode shapes stored in Universal File format. Either analytical data (real normal modes) or experimental data (complex modes) can be used. An option to compute "amplitude-weighted MAC" is also available. This relatively new parameter is useful for differentiating local modes from global modes having similar mode shapes at the measurement locations. A set of analytical, global reference modes are necessary to calculate amplitude-weighted MAC.

MAC is simply the square of the correlation coefficient between mode shapes ϕ_1 and ϕ_2 defined as:

$$\mu = \frac{\left|\phi_1{}^H \phi_2\right|^2}{\left(\phi_1{}^H \phi_1\right)\left(\phi_2{}^H \phi_2\right)} \tag{3-10}$$

where H denotes the Hermitian transpose.

Orthogonality, γ, is similar to MAC except includes the physical mass matrix, M:

$$\gamma = \frac{\left|\phi_1{}^H M \phi_2\right|}{\sqrt{\phi_1{}^H M \phi_1}\sqrt{\phi_2{}^H M \phi_2}} \tag{3-11}$$

The amplitude-weighted MAC is MAC multiplied by the Modal Scale Factor (MSF), μ_A, defined as follows:

$$\mu_A = \frac{\left|\phi_{GR}{}^H \phi\right|}{\left(\phi_{GR}{}^H \phi_{GR}\right)} \tag{3-12}$$

where ϕ_{GR} is a global (analytical) reference mode and ϕ is any experimentally identified mode.

GO input file P25_TA_20_50_DEMO.COM computes test versus analysis MAC values for the Mini-Mast demonstration problem (20-50 Hz data).

Here is a listing of this file:

```
$! P25_TA_20_50_DEMO.COM
$!
$ RUN ERA$EXES:ERAP25
88INIT_20_50  .UNV FILE 1 (PUT BRIEF DESCRIP. ON NEXT LINE)
INITIAL ERA RESULTS
1           FIRST REC. NO. TO READ FROM FILE #1
10000       LAST  REC. NO. TO READ FROM FILE #1
ERA$MMST_NAS:MMST_NASEIGV_900110_TESTDOFS  .UNV FILE 2 (DESCRIP. ON NEXT LINE)
NASTRAN
117         FIRST REC. NO. TO READ FROM FILE #2
129         LAST  REC. NO. TO READ FROM FILE #2
0           FOR AXIS LABEL: 0=FILE NAME & DESCRIP. 1=DESCRIP. ONLY
0           TYPE OF CORRELATION.  0=TEST-ANALYSIS, 1=TEST-TEST, 2=ANALY.-ANALY.
1           WHICH FILE CONTAINS THE TEST RESULTS ?
1           ANALYSIS TYPE?  0=ORTHOGONALITY,1=MAC,2=AMPL. WEIGHTED MAC
ERA$MMST_NAS:MMST.LOC    LOCATION TRACE FILE W/TEST-ANALYSIS MAPPING
1           PRINT OUT THIS MAPPING FILE? 1=YES
90          MINIMUM MAC TO PRINT IN SUMMARY
1           SAVE MAC RESULTS IN A FILE FOR PLOTTING WITH ERAG25?  1=YES
TEMP.MAC    FILE NAME FOR SAVED RESULTS
1           PRINT OUT COMPLETE MAC MATRIX ?  1=YES
0           PRINT OUT TOP 5 CORRELATED FILE 1 MODES?  1=YES
1           PRINT DAMPED (1) OR UNDAMPED (2) NATURAL FREQUENCIES ?
```

Copy this file into your default directory and execute it using GO:

```
COPY ERA$GO:P25_TA_20_50_DEMO.COM []

GO P25_TA_20_50_DEMO
```

The following information appears on your computer screen when P25_TA_20_50_DEMO is run:

```
ERAP25. CALCULATE CORRELATION COEFFICIENTS (MAC OR ORTHOGONALITY)
        BETWEEN MODE SHAPES IN TWO TYPE 55 .UNV FILES
```

```
FILE NAME OF UNIVERSAL FILE #1 ? [DEFAULT FILE TYPE = .UNV]
88INIT_20_50.UNV

30-CHARACTER (MAX.) DESCRIPTION OF FILE #1 ?
INITIAL ERA RESULTS

FIRST MODE-SHAPE RECORD NO. TO READ FROM FILE #1 ?  (1)
         1

LAST MODE-SHAPE RECORD NO. TO READ FROM FILE #1 ?
[ENTER A LARGE NO. TO READ COMPLETE FILE]  (100000)
      10000

FILE NAME OF UNIVERSAL FILE #2 ? [DEFAULT FILE TYPE = .UNV]
ERA$MMST_NAS:MMST_NASEIGV_900110_TESTDOFS.UNV

30-CHARACTER (MAX.) DESCRIPTION OF FILE #2 ?
NASTRAN

FIRST MODE-SHAPE RECORD NO. TO READ FROM FILE #2 ?  (1)
        117

LAST MODE-SHAPE RECORD NO. TO READ FROM FILE #2 ?
[ENTER A LARGE NO. TO READ COMPLETE FILE]  (100000)
        129

FOR AXES LABELS, USE:  (0)
 0. FILE NAME & DESCRIPTION
 1. DESCRIPTION ONLY
          0

TYPE OF COMPARISON ?  (0)
 0 - TEST VS ANALYSIS
 1 - TEST VS TEST
 2 - ANALYSIS VS ANALYSIS
          0

WHICH FILE CONTAINS THE TEST RESULTS ?  (1)
          1

WHICH CALCULATION SHOULD BE PERFORMED ?  (0)
 0 = ORTHOGONALITY
 1 = MODAL ASSURANCE CRITERION (MAC)
 2 = AMPLITUDE-WEIGHTED MAC
          1

NAME OF LOCATION TRACE DEFINING CORRESPONDING TEST-ANALYSIS LOCATION NOS. ?
[DEFAULT FILE TYPE = .LOC]
ERA$MMST_NAS:MMST.LOC

NCOORD =    53


PRINT OUT THIS MAPPING FILE?  1=YES (1)
          1
```

TEST LOCATION NOS.	CORRESPONDING ANALYSIS LOCATION NOS.	INCLUDE DOFS
1	40	110
2	41	110
3	42	110
4	58	110
5	59	110
6	60	110
7	76	110
8	77	110
9	78	110
10	94	110
11	95	110
12	96	110
13	112	110
14	113	110
15	114	110
16	130	110
17	131	110
18	132	110
19	148	110
20	149	110
21	150	110
22	166	110
23	167	110
24	168	110
25	184	110
26	185	110
27	186	110
28	202	110
29	203	110
30	204	110
31	220	110
32	221	110
33	222	110

```
          34                  238                 110
          35                  239                 110
          36                  240                 110
          37                  256                 110
          38                  257                 110
          39                  258                 110
          40                  274                 110
          41                  275                 110
          42                  276                 110
          43                  292                 110
          44                  293                 110
          45                  294                 110
          46                  310                 110
          47                  311                 110
          48                  312                 110
          49                  328                 110
          50                  329                 110
          51                  330                 110
         201                100201                   1
         203                100203                   1

MINIMUM CORRELATION COEFFICIENT (%) TO PRINT AS A SUMMARY ?  (80.0)
  90.00000

SHOULD COMPLETE CORRELATION RESULTS BE SAVED IN A FILE
FOR PLOTTING WITH ERAG25 ?  1=YES  (0)
        1

FILE NAME FOR SAVING COMPLETE CORRELATION RESULTS ?
DEFAULT FILE TYPE = .MAC]
TEMP.MAC

PRINT OUT FULL CORRELATION MATRIX ?  1=YES  (0)
        1

DO YOU WANT THE TOP 5 CORRELATED FILE 1 MODES TO BE PRINTED OUT ? 1=YES (0)
        0

PRINT OUT DAMPED (1) OR UNDAMPED (2) NATURAL FREQS. ?  (1)
        1

SEARCHING FOR RECORD NUMBER     1 ...


READING FILE 1 --- 88INIT_20_50.UNV  ( INITIAL ERA RESULTS )

REC.   1:  FD =  20.013 HZ,  ZETA =  8.078 %     (CASE NO./E.V. NO. =  1/  1)
REC.   2:  FD =  20.303 HZ,  ZETA = 48.674 %     (CASE NO./E.V. NO. =  1/  2)
REC.   3:  FD =  21.571 HZ,  ZETA =  0.906 %     (CASE NO./E.V. NO. =  1/  3)
REC.   4:  FD =  23.536 HZ,  ZETA =  1.168 %     (CASE NO./E.V. NO. =  1/  4)
REC.   5:  FD =  28.628 HZ,  ZETA =  1.109 %     (CASE NO./E.V. NO. =  1/  5)
REC.   6:  FD =  30.717 HZ,  ZETA =  0.992 %     (CASE NO./E.V. NO. =  1/  6)
REC.   7:  FD =  32.069 HZ,  ZETA =  1.002 %     (CASE NO./E.V. NO. =  1/  7)
REC.   8:  FD =  36.908 HZ,  ZETA =  3.482 %     (CASE NO./E.V. NO. =  1/  8)
REC.   9:  FD =  39.005 HZ,  ZETA =  1.022 %     (CASE NO./E.V. NO. =  1/  9)
REC.  10:  FD =  42.227 HZ,  ZETA =  1.003 %     (CASE NO./E.V. NO. =  1/ 10)
REC.  11:  FD =  44.860 HZ,  ZETA =  0.971 %     (CASE NO./E.V. NO. =  1/ 11)
REC.  12:  FD =  49.701 HZ,  ZETA = 34.119 %     (CASE NO./E.V. NO. =  1/ 12)

* * * END OF FILE ENCOUNTERED * * *

  12 MODES PROCESSED


READING FILE 2 --- ERA$MMST_NAS:MMST_NASEIGV_900110_TESTDOFS.UNV  ( NASTRAN )

REC. 117:  FN =  20.308 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/  1)
REC. 118:  FN =  21.570 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/  2)
REC. 119:  FN =  23.474 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/  3)
REC. 120:  FN =  28.648 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/  4)
REC. 121:  FN =  30.721 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/  5)
REC. 122:  FN =  32.064 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/  6)
REC. 123:  FN =  37.335 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/  7)
REC. 124:  FN =  38.309 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/  8)
REC. 125:  FN =  38.322 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/  9)
REC. 126:  FN =  38.322 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/ 10)
REC. 127:  FN =  39.012 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/ 11)
REC. 128:  FN =  42.222 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/ 12)
REC. 129:  FN =  44.856 HZ,  ZETA =  0.000 %     (CASE NO./E.V. NO. =  0/ 13)

  13 MODES PROCESSED

BEGINNING MAC CALCULATION
DOT FIRST INTO SECOND
FILE 1: CASE =  1
DOT FIRST INTO FIRST
DOT SECOND INTO SECOND
FILE 2: CASE =  0

FILE #1: 88INIT_20_50.UNV  ( INITIAL ERA RESULTS )

     #2: ERA$MMST_NAS:MMST_NASEIGV_900110_TESTDOFS.UNV  ( NASTRAN )
```

ALL MODE PAIRS WITH CORRELATION .GE. 90.0:

MAC	REC. NOS.		FN, HZ		FD, HZ		ZETA,%	
100.00	3	2	21.572	21.570	21.571	21.570	0.906	0.000
99.83	4	3	23.537	23.474	23.536	23.474	1.168	0.000
99.98	5	4	28.630	28.648	28.628	28.648	1.109	0.000
100.00	6	5	30.718	30.721	30.717	30.721	0.992	0.000
100.00	7	6	32.070	32.064	32.069	32.064	1.002	0.000
99.95	9	11	39.007	39.012	39.005	39.012	1.022	0.000
100.00	10	12	42.230	42.222	42.227	42.222	1.003	0.000
100.00	11	13	44.862	44.856	44.860	44.856	0.971	0.000

FULL CORRELATION MATRIX (FD LISTED):

88INIT_20_50.UNV -- ERA$MMST_NAS:MMST_NASEIGV_900110_TESTDOFS.UNV -->

(INITIAL ERA RESULTS) (NASTRAN)

		1	2	3	4	5	6	7	8	9	10	11	12	13
	V	20.308	21.570	23.474	28.648	30.721	32.064	37.335	38.309	38.322	38.322	39.012	42.222	44.856
1	20.013	8	7	30	15	0	13	7	0	0	0	3	4	1
2	20.303	11	6	6	4	11	4	4	2	3	4	0	14	3
3	21.571	41	100*	44	2	0	0	0	2	2	1	0	0	0
4	23.536	1	40	100*	58	0	32	25	1	1	2	3	0	8
5	28.628	9	2	56	100*	20	50	57	4	5	2	3	1	7
6	30.717	3	0	0	20	100*	0	8	16	18	46	0	0	0
7	32.069	15	0	31	51	0	100*	80	7	7	0	0	0	0
8	36.908	8	0	25	51	5	83	86	15	15	6	6	0	2
9	39.005	3	0	3	3	0	0	6	71	68	1	100*	0	0
10	42.227	0	0	0	1	0	0	0	0	0	1	0	100*	0
11	44.860	6	0	7	7	0	0	2	0	0	37	0	0	100*
12	49.701	7	12	4	1	3	3	0	1	1	1	0	1	2

Program ERAP25 prints the MAC matrix on the last page (p. 3) of the listing. A DIGLIB plot of these results can be obtained using GO Input file G25_DEMO.COM. This file reads a temporary file named TEMP.MAC that was written using P25_TA_20_50_DEMO.

Copy file G25_DEMO.COM into your default directory and execute it as follows:

```
COPY ERA$GO:G25_DEMO.COM []

GO G25_DEMO
```

Fig. 3-7 shows the resulting plot. MAC values are plotted using a simple graphical format. Each row and column represents one mode shape. The value of MAC is proportional to the size of the rectangle drawn at the intersection of the corresponding row and column. Darkened areas highlight MAC values greater than a user-specified threshold. In this example, the threshold is set to 0.7. That is, all MAC values greater than 0.7 are darkened. All NASTRAN modes are accurately identified except the 20.3 Hz mode near the lower frequency limit (20 Hz) and the 3 modes at approximately 38.3 Hz. Multiple

correlations occur for some modes because the accelerometer set is insufficient to ensure unique correlation.

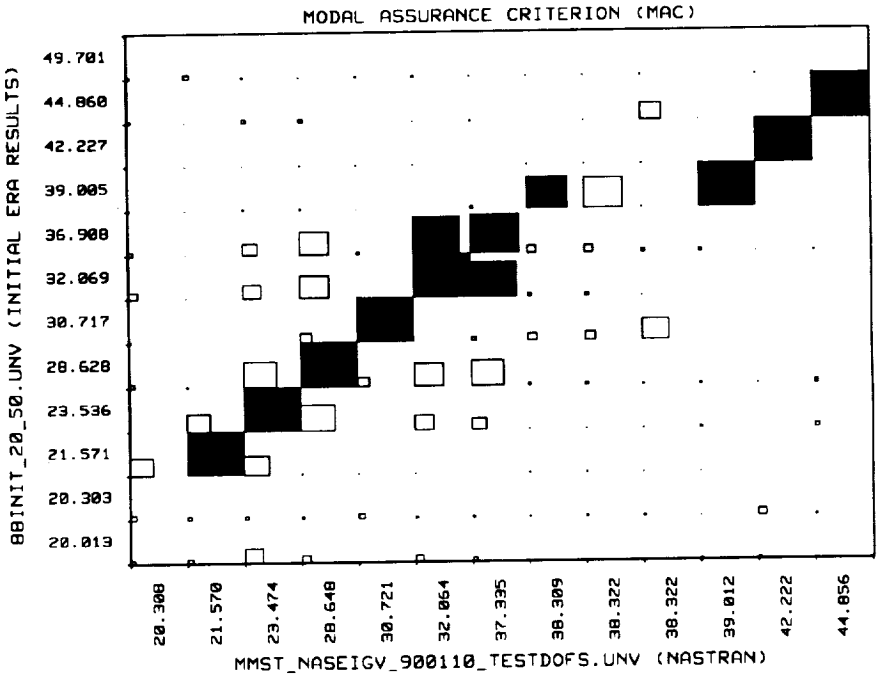


Fig. 3-7. Test vs Analysis MAC Plot [P25_TA_20_50_DEMO and G25_DEMO]

Here is a listing of file G25_DEMO.COM:

```
$!  G25_DEMO.COM
$!
$ RUN ERA$EXES:ERAG25
TEMP.MAC
4       PLOT TYPE.  4=OVERVIEW (ALL MODES ON 1 PAGE)
0.25    CHARACTER SIZE IN CM.
70      CORRELATION TOLERANCE FOR FILLED SQUARES  (%)
1       FONT TYPE.  1=STICK
0       INCLUDE CASE AND E.V. NOS. ON PLOT?  1=YES
0       DRAW VERT. LINES AT START OF EACH NEW CASE IN FILE #2 ?  1=YES
```

The following information appears on your computer screen when G25_DEMO is run:

```
ERAG25. PLOT MAC OR ORTHOGONALITY RESULTS
GENERATED BY ERAP25.

ENTER FILE NAME WHICH CONTAINS MATRIX INFORMATION
[DEFAULT FILE TYPE = .MAC]
TEMP.MAC
```

```
TEMP.MAC

ENTER PLOT TYPE:  (4)
 1 - STANDARD MATRIX PLOT
 2 - BAR CHART OF BEST VALUES
 3 - CONVERGENCE PLOT OF BEST VALUES PER CASE
 4 - OVERVIEW MATRIX PLOT (ALL MODES ON ONE PAGE)
 0 - EXIT PROGRAM
          4

CHARACTER SIZE IN CM. ?  (0.25)
 0.2500000

ENTER CORRELATION TOLERANCE FOR FILLED SQUARES, %  (50)
         70

ENTER FONT TYPE:  (1)
 1 - STICK FONT
 2 - ROMAN SERIF
 3 - ROMAN
          1

INCLUDE CASE NOS. & E.V. NOS. ON PLOT ? 1=YES.  (1)
          0

DRAW VERTICAL LINE AT THE START OF EACH
NEW CASE IN FILE #2 ?  1=YES  (1)
          0

GRAPHICS DEVICE NUMBER ?  (4)
  1 = TEK. 4010
  2 = TEK. 4014
  3 = TEK. 4025
  4 = TEK. 4107
  5 = TEK. 4115B
  6 = HP 2647/2648
  7 = DEC VT240
  8 = HPGL TALL
  9 = HPGL WIDE
 10 = POSTSCRIPT TALL
 11 = POSTSCRIPT WIDE
```

Amplitude-weighted MAC values (Eqs. 3-10 & 3-12) can be generated similarly using GO Input files P25_TA_20_50_GLOBAL_DEMO.COM and G25_DEMO.COM (again). **Fig. 3-8** shows these results. A unique one-to-one pairing of the ERA results (plotted along the y axis) occurs with the 6 global, analytical modes in this frequency interval (plotted along the x axis). Global modes dominate amplitude-weighted MAC results because, in general, they have larger response amplitudes than local modes.

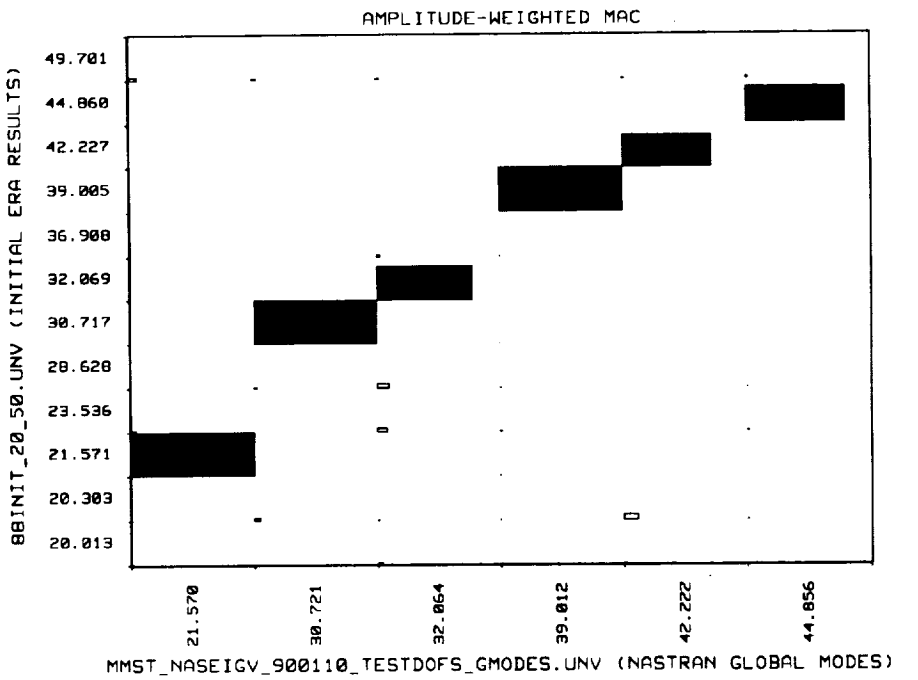


Fig. 3-8. Amplitude-Weighted MAC Plot [P25_TA_20_50_GLOBAL_DEMO and G25_DEMO]

3.9 Mode Shape Plotting (ERAG5 or ERAG50)

Three methods are available for plotting mode shapes:

1. Printer plots of amplitude and phase versus measurement number written to Tape51 (or, optionally, to Tape50 by specifying MSTO50 = 1).

2. DIGLIB plots of amplitude and phase versus measurement number generated from data on Tape88 (.UNV file) using post-processor program ERAG5 (or, optionally, from data on Tape51 using program ERAG5B).

3. DIGLIB "wireframe" plots of deformed and/or undeformed shapes generated from data on Tape88 (.UNV file) using post-processor program ERAG50. Geometry and connectivity information for ERAG50 is provided as ASCII files (FORTRAN free-field format) or as Type 15 and Type 82 .UNV files, respectively.

The following 3 report sections describe these 3 types of mode shape plots.

NOTE: *There is currently no capability to animate mode shapes with the ERA software.* Animations can be obtained, however, using a variety of commercial software packages such as the SDRC TDAS or LMS CADA programs. These programs can read the Tape88 (.UNV) mode shape files generated by ERA.

3.9.1 Printer Plots on Tape51 (or Tape50)

In some applications, mode shape results are more easily understood using simple amplitude and phase versus measurement number plots than using traditional deformed geometry ("wireframe") plots. These plots are available as either ASCII "printer plots" on Tape50 or Tape51 (discussed in this section) or as DIGLIB plots generated using data read from either Tape88 (.UNV) or Tape51 files (discussed in the following section).

Mode shape "printer plots" are written to Tape51 by specifying ITAPES=51 in Field 4 of the ERA User Input file; i.e., by activating Tape51. Optionally, these results can be written to Tape50 by specifying MSTO50 = 1. MSTO50 is an acronym for "Mode Shapes to Tape50." To obtain only the tabulated mode-shape information on Tape50 (i.e., skip the printer plot portion), also specify MSPP50 = 0 which deactivates the printer plots. By default, MSPP50 = 1. MSPP50 is an acronym for "Mode Shape Printer Plots to Tape50."

Tape51 results for the second torsion mode of Mini-Mast at 21.571 Hz are shown on the following 3 pages. This mode is Eigenvalue No. 3 from file 51INIT_20_50.LIS. The tabulated mode shape occurs first followed by a plot using asterisks. The tabulation includes both the normalized mode shape and the mode shape in engineering units for each of the 3 data sets (inputs) included in the analysis. Initial physical amplitudes are the identified initial amplitudes in engineering units of the impulse response functions (or free-decay data) on a mode-by-mode basis. The normalized mode shape has a maximum amplitude of 100.0 (with positive phase angle) and the phase angles are rotated to align best with +/- 90 degrees using the method described in Section 2.6.3.2. **Note that the mode-shape printer plot is not a conventional plot of magnitude (>= 0) and corresponding phase angle.** *The amplitude data also contains polarity (phase) information so that the relative deformation pattern can be directly observed.* Mode shape components with positive phase angles are positive amplitudes and mode shape components with negative phase angles are negative amplitudes.

The final line of the tabulation shows normalized modal participation factors. These quantities are the relative response magnitudes among the 3 data sets (inputs) included in

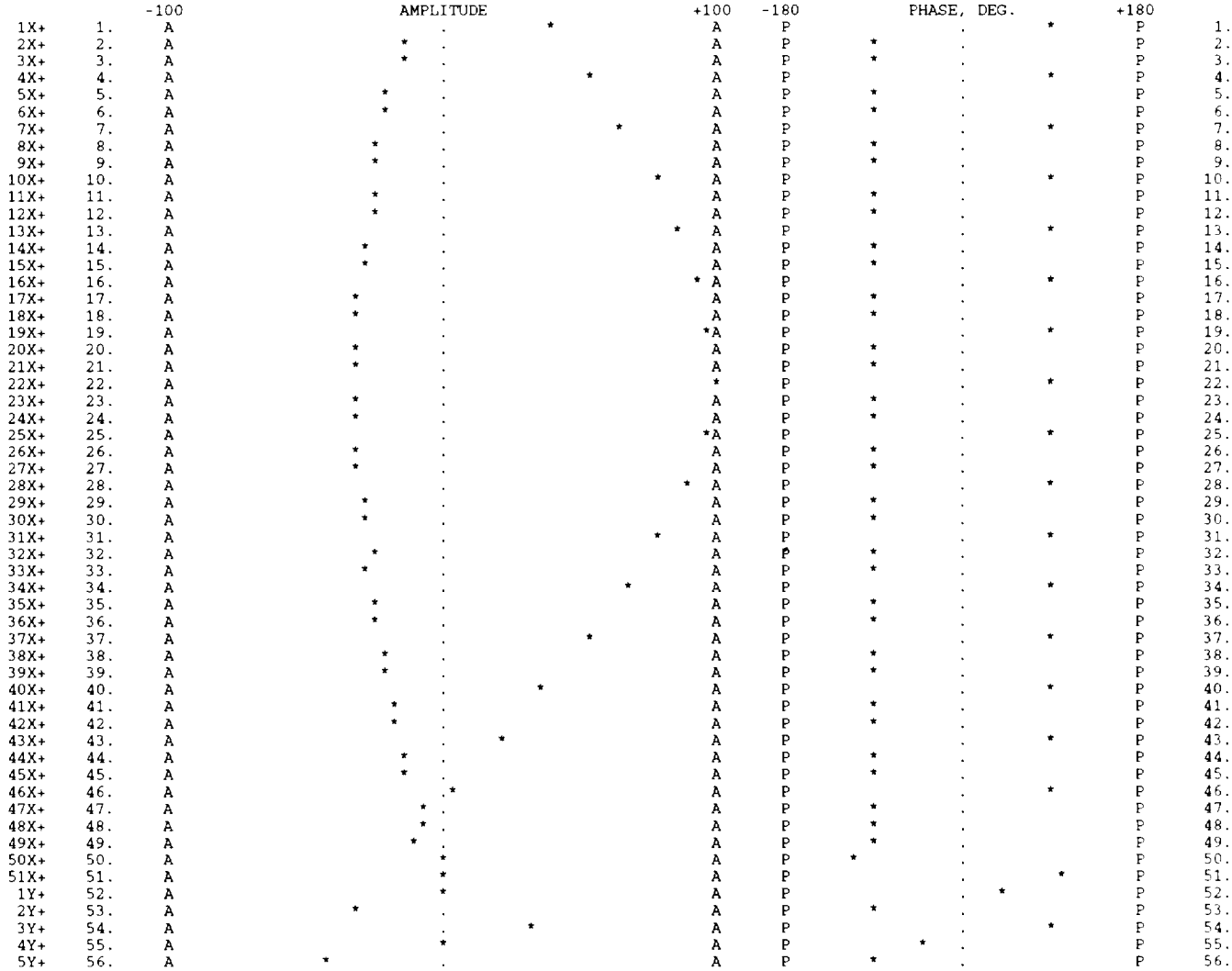
the analysis. The phase angle is the angle by which the corresponding mode shape in engineering units differs from the normalized mode shape.

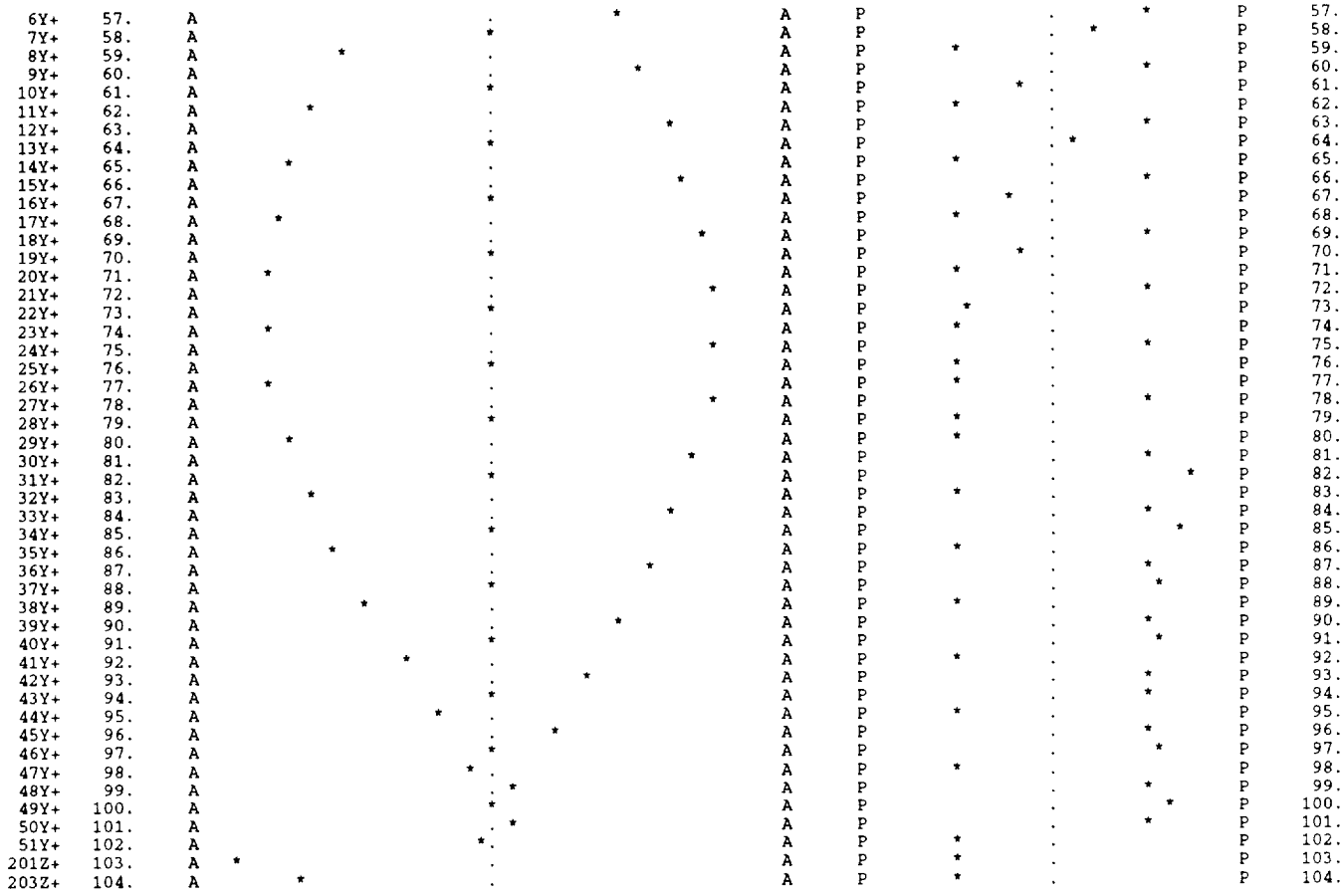
File 51INIT_20_50.LIS (partial)

EIGENVALUE NO. 3 FREQUENCY = 21.571 HZ

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE		INITIAL PHYSICAL AMPLITUDES IC # 1	201Z+	IC # 2	23Y+	IC # 3	203Z+
3	21.571*	0.906	1X+	1	39.06	90.1	3.6369E-05	-89.6	3.2177E-05	-89.9	2.7492E-05	-88.9
			2X+	2	15.32	-90.0	1.4269E-05	90.4	1.2624E-05	90.0	1.0786E-05	91.0
			3X+	3	15.39	-89.9	1.4335E-05	90.4	1.2682E-05	90.1	1.0835E-05	91.1
			4X+	4	53.73	90.0	5.0033E-05	-89.7	4.4265E-05	-90.1	3.7820E-05	-89.1
			5X+	5	20.22	-90.0	1.8826E-05	90.4	1.6656E-05	90.0	1.4231E-05	91.0
			6X+	6	20.04	-90.0	1.8665E-05	90.3	1.6513E-05	90.0	1.4109E-05	90.9
			7X+	7	65.61	90.1	6.1090E-05	-89.6	5.4048E-05	-90.0	4.6178E-05	-89.0
			8X+	8	23.11	-90.1	2.1521E-05	90.2	1.9040E-05	89.9	1.6267E-05	90.9
			9X+	9	23.29	-90.0	2.1682E-05	90.4	1.9183E-05	90.0	1.6390E-05	91.0
			10X+	10	77.69	90.0	7.2339E-05	-89.6	6.4001E-05	-90.0	5.4681E-05	-89.0
			11X+	11	26.67	-90.1	2.4831E-05	90.2	2.1969E-05	89.9	1.8770E-05	90.9
			12X+	12	26.42	-90.1	2.4600E-05	90.2	2.1765E-05	89.9	1.8595E-05	90.9
			13X+	13	86.05	90.0	8.0123E-05	-89.6	7.0888E-05	-90.0	6.0565E-05	-89.0
			14X+	14	28.07	-90.1	2.6141E-05	90.2	2.3128E-05	89.8	1.9760E-05	90.8
			15X+	15	28.37	-90.1	2.6416E-05	90.2	2.3371E-05	89.9	1.9968E-05	90.9
			16X+	16	93.88	90.0	8.7419E-05	-89.7	7.7342E-05	-90.0	6.6080E-05	-89.0
			17X+	17	30.34	-90.0	2.8252E-05	90.4	2.4995E-05	90.0	2.1355E-05	91.0
			18X+	18	30.07	-90.1	2.7999E-05	90.2	2.4771E-05	89.9	2.1164E-05	90.9
			19X+	19	97.50	90.0	9.0786E-05	-89.6	8.0321E-05	-90.0	6.8625E-05	-89.0
			20X+	20	30.48	-90.0	2.8383E-05	90.3	2.5111E-05	90.0	2.1454E-05	90.9
			21X+	21	30.71	-90.0	2.8599E-05	90.3	2.5302E-05	90.0	2.1618E-05	91.0
			22X+	22	100.00	90.0	9.3115E-05	-89.7	8.2382E-05	-90.0	7.0386E-05	-89.0
			23X+	23	31.62	-90.1	2.9443E-05	90.3	2.6049E-05	89.9	2.2256E-05	90.9
			24X+	24	31.42	-89.9	2.9255E-05	90.4	2.5883E-05	90.0	2.2114E-05	91.0
			25X+	25	97.79	90.0	9.1056E-05	-89.7	8.0560E-05	-90.0	6.8829E-05	-89.0
			26X+	26	30.83	-90.0	2.8710E-05	90.4	2.5400E-05	90.0	2.1702E-05	91.0
			27X+	27	30.80	-89.9	2.8679E-05	90.4	2.5373E-05	90.1	2.1678E-05	91.0
			28X+	28	90.06	90.0	8.3864E-05	-89.7	7.4197E-05	-90.0	6.3393E-05	-89.1
			29X+	29	29.11	-89.7	2.7104E-05	90.6	2.3980E-05	90.2	2.0488E-05	91.2
			30X+	30	28.91	-89.9	2.6923E-05	90.4	2.3820E-05	90.1	2.0351E-05	91.0
			31X+	31	80.02	90.0	7.4507E-05	-89.7	6.5919E-05	-90.1	5.6320E-05	-89.1
			32X+	32	26.98	-90.0	2.5124E-05	90.3	2.2228E-05	90.0	1.8991E-05	91.0
			33X+	33	27.22	-89.8	2.5345E-05	90.5	2.2423E-05	90.1	1.9158E-05	91.1
			34X+	34	67.22	90.0	6.2594E-05	-89.6	5.5379E-05	-90.0	4.7315E-05	-89.0
			35X+	35	24.29	-89.8	2.2622E-05	90.5	2.0014E-05	90.2	1.7100E-05	91.2
			36X+	36	24.21	-89.9	2.2542E-05	90.5	1.9944E-05	90.1	1.7040E-05	91.1
			37X+	37	53.24	90.0	4.9571E-05	-89.6	4.3857E-05	-90.0	3.7471E-05	-89.0
			38X+	38	21.02	-90.0	1.9577E-05	90.3	1.7321E-05	89.9	1.4799E-05	90.9
			39X+	39	21.15	-90.1	1.9694E-05	90.2	1.7424E-05	89.9	1.4886E-05	90.9
			40X+	40	37.56	90.1	3.4973E-05	-89.6	3.0942E-05	-89.9	2.6436E-05	-88.9
			41X+	41	17.14	-90.1	1.5955E-05	90.2	1.4116E-05	89.9	1.2061E-05	90.9
			42X+	42	17.03	-90.3	1.5859E-05	90.1	1.4031E-05	89.7	1.1988E-05	90.7
			43X+	43	22.03	90.1	2.0512E-05	-89.6	1.8148E-05	-90.0	1.5505E-05	-89.0
			44X+	44	12.47	-90.2	1.1609E-05	90.1	1.0271E-05	89.8	8.7753E-06	90.7
			45X+	45	12.44	-90.7	1.1586E-05	89.7	1.0250E-05	89.3	8.7575E-06	90.3
			46X+	46	5.65	90.7	5.2630E-06	-89.0	4.6563E-06	-89.3	3.9783E-06	-88.3
			47X+	47	7.02	-90.8	6.5378E-06	89.5	5.7842E-06	89.2	4.9420E-06	90.2
			48X+	48	6.86	-90.9	6.3867E-06	89.4	5.6505E-06	89.1	4.8277E-06	90.1
			49X+	49	11.06	-90.4	1.0300E-05	89.9	9.1130E-06	89.6	7.7860E-06	90.5
			50X+	50	0.37	-110.5	3.4306E-07	69.8	3.0352E-07	69.5	2.5932E-07	70.5
			51X+	51	0.90	100.8	8.3464E-07	-78.9	7.3843E-07	-79.2	6.3091E-07	-78.2
			1Y+	52	0.13	40.8	1.1930E-07	-138.8	1.0555E-07	-139.2	9.0177E-08	-138.2
			2Y+	53	31.34	-89.8	2.9180E-05	90.5	2.5816E-05	90.1	2.2057E-05	91.1
			3Y+	54	31.41	89.9	2.9252E-05	-89.8	2.5880E-05	-90.1	2.2111E-05	-89.1
			4Y+	55	0.19	-37.2	1.8104E-07	143.1	1.6017E-07	142.8	1.3685E-07	143.8
			5Y+	56	42.66	-89.8	3.9725E-05	90.6	3.5146E-05	90.2	3.0028E-05	91.2
			6Y+	57	42.68	89.8	3.9744E-05	-89.8	3.5163E-05	-90.2	3.0042E-05	-89.2
			7Y+	58	0.22	40.1	2.0929E-07	-139.6	1.8516E-07	-139.9	1.5820E-07	-138.9
			8Y+	59	51.33	-89.8	4.7796E-05	90.6	4.2286E-05	90.2	3.6129E-05	91.2
			9Y+	60	51.23	89.8	4.7699E-05	-89.8	4.2201E-05	-90.2	3.6056E-05	-89.2
			10Y+	61	0.22	-31.8	2.0646E-07	148.5	1.8266E-07	148.2	1.5606E-07	149.1
			11Y+	62	60.06	-89.8	5.5929E-05	90.5	4.9482E-05	90.2	4.2277E-05	91.2
			12Y+	63	60.22	89.8	5.6078E-05	-89.9	4.9614E-05	-90.2	4.2390E-05	-89.2
			13Y+	64	0.21	20.7	1.9872E-07	-159.0	1.7581E-07	-159.4	1.5021E-07	-158.4
			14Y+	65	66.12	-89.8	6.1565E-05	90.6	5.4468E-05	90.2	4.6537E-05	91.2
			15Y+	66	65.80	89.8	6.1266E-05	-89.9	5.4203E-05	-90.2	4.6311E-05	-89.2
			16Y+	67	0.31	-43.2	2.9309E-07	137.1	2.5930E-07	136.7	2.2154E-07	137.7
			17Y+	68	71.62	-89.9	6.6685E-05	90.5	5.8998E-05	90.1	5.0407E-05	91.1
			18Y+	69	71.64	89.8	6.6712E-05	-89.9	5.9022E-05	-90.2	5.0428E-05	-89.2
			19Y+	70	0.20	-28.8	1.8611E-07	151.5	1.6466E-07	151.2	1.4068E-07	152.1
			20Y+	71	74.21	-89.9	6.9098E-05	90.4	6.1133E-05	90.1	5.2231E-05	91.1
			21Y+	72	73.59	89.8	6.8523E-05	-89.9	6.0624E-05	-90.2	5.1796E-05	-89.3
			22Y+	73	0.45	-84.7	4.2038E-07	95.6	3.7192E-07	95.3	3.1776E-07	96.3

23Y+	74	76.08	-90.0	7.0840E-05	90.4	6.2674E-05	90.0	5.3548E-05	91.0
24Y+	75	75.91	89.9	7.0680E-05	-89.7	6.2533E-05	-90.1	5.3427E-05	-89.1
25Y+	76	0.57	-89.6	5.3134E-07	90.8	4.7009E-07	90.4	4.0164E-07	91.4
26Y+	77	74.82	-90.0	6.9668E-05	90.3	6.1638E-05	90.0	5.2662E-05	91.0
27Y+	78	73.63	90.0	6.8557E-05	-89.7	6.0655E-05	-90.0	5.1822E-05	-89.0
28Y+	79	0.32	-94.7	3.0082E-07	85.6	2.6615E-07	85.2	2.2739E-07	86.2
29Y+	80	68.86	-90.0	6.4121E-05	90.3	5.6730E-05	90.0	4.8469E-05	90.9
30Y+	81	68.56	90.1	6.3836E-05	-89.5	5.6478E-05	-89.9	4.8254E-05	-88.9
31Y+	82	0.33	133.2	3.1134E-07	-46.5	2.7545E-07	-46.8	2.3534E-07	-45.8
32Y+	83	61.69	-90.2	5.7438E-05	90.1	5.0817E-05	89.8	4.3417E-05	90.8
33Y+	84	61.82	90.1	5.7564E-05	-89.6	5.0929E-05	-90.0	4.3513E-05	-89.0
34Y+	85	0.67	116.8	6.2538E-07	-62.8	5.5329E-07	-63.2	4.7272E-07	-62.2
35Y+	86	52.01	-90.2	4.8429E-05	90.2	4.2847E-05	89.8	3.6608E-05	90.8
36Y+	87	53.51	90.2	4.9822E-05	-89.5	4.4079E-05	-89.8	3.7660E-05	-88.9
37Y+	88	1.36	100.4	1.2635E-06	-79.3	1.1179E-06	-79.7	9.5511E-07	-78.7
38Y+	89	41.80	-90.3	3.8922E-05	90.1	3.4436E-05	89.7	2.9421E-05	90.7
39Y+	90	44.15	90.3	4.1113E-05	-89.3	3.6374E-05	-89.7	3.1077E-05	-88.7
40Y+	91	1.55	97.7	1.4415E-06	-82.0	1.2753E-06	-82.3	1.0896E-06	-81.3
41Y+	92	29.95	-90.4	2.7892E-05	89.9	2.4676E-05	89.6	2.1083E-05	90.6
42Y+	93	33.27	90.5	3.0976E-05	-89.1	2.7405E-05	-89.5	2.3414E-05	-88.5
43Y+	94	2.00	93.9	1.8612E-06	-85.8	1.6467E-06	-86.1	1.4069E-06	-85.2
44Y+	95	18.00	-90.6	1.6763E-05	89.7	1.4831E-05	89.4	1.2671E-05	90.3
45Y+	96	21.80	90.5	2.0302E-05	-89.2	1.7961E-05	-89.5	1.5346E-05	-88.5
46Y+	97	1.56	95.4	1.4517E-06	-84.3	1.2844E-06	-84.7	1.0973E-06	-83.7
47Y+	98	5.65	-91.7	5.2574E-06	88.7	4.6514E-06	88.3	3.9741E-06	89.3
48Y+	99	8.84	90.7	8.2346E-06	-89.0	7.2854E-06	-89.3	6.2246E-06	-88.3
49Y+	100	0.19	114.1	1.7234E-07	-65.5	1.5248E-07	-65.9	1.3027E-07	-64.9
50Y+	101	7.71	90.3	7.1781E-06	-89.3	6.3507E-06	-89.7	5.4259E-06	-88.7
51Y+	102	4.85	-91.2	4.5131E-06	89.1	3.9929E-06	88.8	3.4114E-06	89.8
201Z+	103	86.46	-90.1	8.0506E-05	90.3	7.1226E-05	89.9	6.0854E-05	90.9
203Z+	104	65.13	-90.1	6.0643E-05	90.2	5.3652E-05	89.9	4.5840E-05	90.9
NORMALIZED MODAL PARTICIPATION FACTOR(S):				100.00	0.3	88.47	0.0	75.59	1.0





3.9.2 DIGLIB Magnitude and Phase Plots (ERAG5)

Post-processor program ERAG5 generates DIGLIB mode shape plots of amplitude and phase versus measurement number using data read from the Tape88 (.UNV) output file.[118] The plot format is identical to the "printer plots" on Tape51 that were discussed in Section 3.9.1.[119] **Fig. 3-9** shows the output of program ERAG5 for the same mode (the second torsion mode of Mini-Mast) printed on the previous 3 pages.

[118]Only modes with CMI values greater than or equal to parameter T88CMI are written to Tape88 during the ERA analysis. The default value of T88CMI is 20 (percent).

[119]Program ERAG5 has essentially superseded program ERAG5B that generates DIGLIB plots using mode shape results on Tape51. ERAG5 has some additional features that have not been incorporated into ERAG5B. Output file Tape51 is now seldom activated. A sample GO Input file named G5B_20_50_DEMO.COM is available for replotting Fig. 3-9 using ERAG5B.

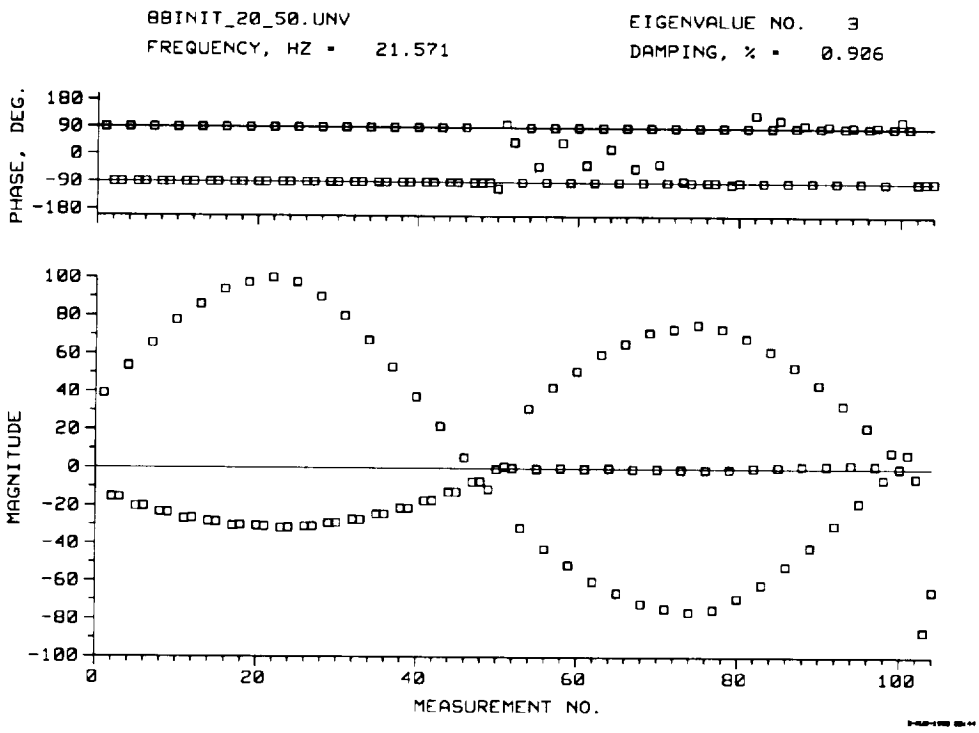


Fig. 3-9. Magnitude and Phase Mode Shape Plot [G5_2T_DEMO]

Fig. 3-9 is generated using GO Input file G5_2T_DEMO.COM. Copy this file into your current default directory (that should also contain the file 88INIT_20_50.UNV generated earlier by executing ERA job INIT_20_50), then execute it as follows:

```
COPY ERA$GO:G5_2T_DEMO.COM []

GO G5_2T_DEMO
```

Here is a listing of file G5_2T_DEMO.COM:

```
$! G5_2T_DEMO.COM
$!
$ RUN ERA$EXES:ERAG5
88INIT_20_50
1      CASE NO. TO USE FROM TAPE88
1      SPECIFY A RANGE(1) OR LIST(2) OF EIGENVALUES?
3      FIRST EIGENVALUE OF RANGE
3      LAST EIGENVALUE OF RANGE (ENTER A LARGE NO. FOR ALL)
1      MODE NORMALIZATION? 0=NONE, 1=NORMALIZED, 0-100 W/PHS ROT.
0      PRINT MODE SHAPE TO FILE G5.OUT?  1=YES
ERA$MMST_NAS:TC_MMST_NAS_SH1  CC FILE FOR CC-TO-MEAS. NO. MAPPING
0      PRINT COORDINATE CODE MAPPING?  1=YES
1      ADJUST POLARITY OF MODE SHAPE COMPS. BASED ON CC SIGNS? 1=YES
1      FIRST MEAS. NO. TO PLOT
```

```
1000   LAST MEAS. NO. TO PLOT  (ENTER LARGE NO. TO PLOT ALL)
2      DELTA FOR X-AXIS MINOR TIC MARKS
10     DELTA FOR Y-AXIS (MAGNITUDE) MINOR TIC MARKS
100    MAX. AMPLITUDE TO PLOT
0.3    CHARACTER SIZE FOR PLOT LABELS, IN CM
1      FONT TYPE. 1=STICK.
0.2    SYMBOL SIZE FOR PLOTTING DATA, IN CM
0      SKIP PHASE PLOT? 1=YES
0      CONNECT MAGNITUDE SYMBOLS WITH LINES?  1=YES
0      CONNECT   PHASE   SYMBOLS WITH LINES?  1=YES
0      SORT MEASUREMENT NOS. BY AMPLITUDE?  1=YES
1      USE DEFAULT OVERALL WINDOW SIZE?  1=YES
```

The following information appears on your computer screen when G5_2T_DEMO is run:

```
ERAG5.  PLOT TYPE 55 UNIVERSAL FILES (TAPE88).
        MODE SHAPES: AMPL. & PHASE VS. MEAS. NO.

TAPE88 FILENAME ? [DEFAULT FILE TYPE = .UNV])
88INIT_20_50.UNV

CASE NO. TO USE FROM TAPE88 ?  (1)
          1

PLOT A RANGE OF EIGENVALUES(1), OR SPECIFY A
LIST OF INDIVIDUAL EIGENVALUE NOS. TO PLOT (2) ?  (1)
          1

FIRST EIGENVALUE NO. TO PLOT ?  (1)
          3

LAST EIGENVALUE NO. TO PLOT ?  (10000)

[ENTER A LARGE NO. TO PLOT ALL EIGENVALUES FOR THIS CASE]
          3

WHICH MODE SHAPE NORMALIZATION DESIRED ?  (0)
 0=UNNORMALIZED
 1=NORMALIZED MAG., 0-100; PHASE ANGLE ROTATED FOR BEST
   FIT NEAR +/- 90 DEG.
 2=NORMALIZE A PARTICULAR MEASUREMENT NO. TO 100% & 90 DEG. PHASE
          1

PRINT MODE SHAPE TO FILE 'G5.OUT' ? 1=YES  (0)
          0

NAME OF COORDINATE-CODE FILE TO USE AS MAPPING FROM COORDINATE CODES
TO MEASUREMENT NOS. ? [DEFAULT FILE TYPE = .DAT])
ERA$MMST_NAS:TC_MMST_NAS_SH1.DAT

PRINT COORDINATE-CODE MAPPING ? 1=YES  (1)
          0
```

```
 NST =    104

 SHOULD POLARITY OF MODE SHAPE COMPONENTS BE ADJUSTED
 BASED ON SIGNS OF THE DIRECTION DATA IN CC FILE ?  1=YES  (1)
           1

 FIRST MEASUREMENT NO. TO PLOT ?  (1)
           1

 LAST MEASUREMENT NO. TO PLOT ?  (10000)
 [ENTER A LARGE NO. TO PLOT ALL]
        1000

 DELTA FOR X-AXIS MINOR TIC MARKS ?  (2)
  [0.0 = NONE]
   2.000000

 DELTA FOR Y-AXIS MINOR TIC MARKS (MAG. PLOT) ?  (2)
  [0.0 = NONE]
   10.00000

 MAX. AMPLITUDE TO PLOT? 0 = AUTOSCALE  (0)
   100.0000

 CHARACTER SIZE (HT.) FOR PLOT LABELS, IN CM ?  (0.3)
  0.3000000

 FONT TYPE ?  (1)
  1 = STICK FONT
  2 = LETTER QUALITY - BOLD
  3 = LETTER QUALITY - STD.
           1

 SYMBOL SIZE FOR PLOTTING DATA, IN CM ?  (0.3)
  0.2000000

 SKIP PHASE PLOT ?  1=YES  (0)
           0

 CONNECT MAGNITUDE SYMBOLS WITH LINES ?  1=YES  (1)
           0

 CONNECT PHASE SYMBOLS WITH LINES ?  1=YES  (1)
           0

 IT IS POSSIBLE TO SORT THE MEASUREMENT NOS. FROM LARGEST TO SMALLEST AMPLITUDE,
 IN ORDER TO EXAMINE THE EXTENT OF PHASE SCATTER VS. AMPLITUDE.
 WOULD YOU LIKE USE THIS OPTION ?  1=YES  (0)
           0

 USE THE DEFAULT OVERALL WINDOW SIZE ? 1=YES  (1)
           1

 GRAPHICS DEVICE NUMBER ?  (4)
```

```
 1 = TEK. 4010
 2 = TEK. 4014
 3 = TEK. 4025
 4 = TEK. 4107
 5 = TEK. 4115B
 6 = HP 2647/2648
 7 = DEC VT240
 8 = HPGL TALL
 9 = HPGL WIDE
10 = POSTSCRIPT TALL
11 = POSTSCRIPT WIDE
```

Program ERAG5 can also plot analytical (NASTRAN) mode shapes. As a demonstration, GO Input file G5_ANAL_2T_DEMO.COM plots the same mode (2nd torsion) from the NASTRAN .UNV file named MMST_NASEIGV_900110_TESTDOFS.UNV. Note that the last 2 measurement numbers in Fig. 3-9 (Nos. 103 & 104) are not available in the NASTRAN .UNV file. They driving point measurements for Shakers 1 and 3 that are not aligned with any of the global coordinate axes. (Additional explanation of Measurement Nos. 103 & 104 appears following the listing of G50_2T_DEMO.COM output in Section 3.9.3.)

3.9.3 Wireframe Mode Shape Plots (ERAG50)

Post-processor program ERAG50 generates traditional "wireframe" mode shape plots. Mode shapes are read from the Tape88 (.UNV) output file.[120] As an example, the second torsion mode of Mini-Mast is once again plotted in **Fig. 3-10**.

NOTE: *There is currently no capability to animate mode shapes with the ERA software.* Animations can be obtained, however, using a variety of commercial software packages such as the SDRC TDAS or LMS CADA programs. These programs can read the Tape88 (.UNV) mode shape files written by ERA.

Fig. 3-10 is generated using GO Input file G50_2T_DEMO.COM. Copy this file into your current default directory (which should also contain output file 88INIT_20_50.UNV generated earlier by ERA job INIT_20_50), then execute it as follows:

```
COPY ERA$GO:G50_2T_DEMO.COM []

GO G50_2T_DEMO
```

[120]Only modes with CMI values greater than or equal to parameter T88CMI are written to Tape88 during the ERA analysis. The default value of T88CMI is 1.0 (percent).

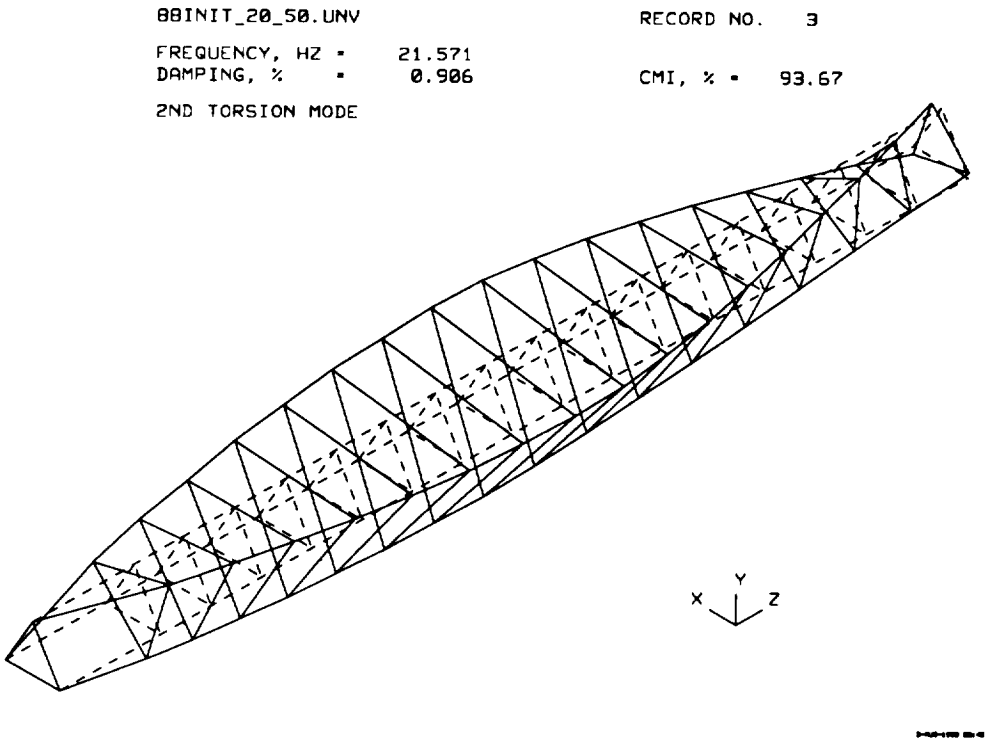


Fig. 3-10. Wireframe Mode Shape Plot [G50_2T_DEMO.COM]

The Mini-Mast truss is cantilevered from its base located at the lower-left of Fig. 3-10. The node line for this second torsion mode occurs near the free end of the truss (in the middle of the last bay at upper-right) due to a massive plate located at the tip.

Here is a listing of file G50_2T_DEMO.COM:

```
$! G50_2T_DEMO.COM
$!
$ RUN ERA$EXES:ERAG50
1    TYPE OF GEOMETRY FILE: 1=ASCII FILE, 2=.UNV FILE
ERA$MMST_NAS:MMST_GEO.DAT       GEOMETRY FILE NAME
1    TYPE OF CONNECTIVITY FILE: 1=ASCII FILE, 2=.UNV FILE
ERA$MMST_NAS:MMST_CON.DAT       CONNECTIVITY FILE NAME
88INIT_20_50    TAPE88 FILE. 'NONE' = STATIC PLOT
1 ROTATE MODES TO +/-90 DEG. BEFORE ANSWERING NEXT QUESTION? 1=YES
1         DISPLAY FORMAT: 1=SIGNED MAGNITUDE, 2=REAL PART, 3=IMAG. PART
3         UNDEFORMED SHAPE AS: 1=SOLID LINE, 2=LONG DASH, 3-SHORT DASH
10.0      MAX. DEFLECTION AS PERCENT OF MAX. DIMENSION OF STRUCTURE
2         STRUCTURE AXIS TO ALIGN W/ DISPLAY Y-AXIS, +/- O.K. (1=X, 2=Y, 3=Z)
-1,1,-1   VIEWING LOCATION (X,Y,Z)
0         PLOT ROTATION ANGLE (CCW) IN DEGREES
0.95      PLOT SIZE.  FULL SIZE = 1.0
0.3       CHARACTER SIZE IN CM
0         TURN ON POINT NUMBERING?  1=YES
```

```
51        DESIRED REF. PT. (REF. PT. & DIR. PLOTTED WITH POSITIVE SENSE)
2         REFERENCE DIRECTION
0         GRID LINES ON? 1=YES
1         LENGTH OF ORIENTATION TRIADE LEGS IN CM
20,3      TRIADE ORIGIN (X,Y) IN CM FROM LOWER-LEFT CORNER OF DISPLAY
2,2,1     FIRST,LAST,STEP EIGENVALUES TO PLOT?  ENTER 0,0,0 TO END
1         WRITE DESCRIPTION ON EACH PLOT? 1=YES
1         FROM WHERE TO READ DESCRIPTIONS? 1=GO INPUT FILE, 2=KEYBOARD
2ND TORSION MODE
```

The information in this GO Input file establishes initial values for various program variables. Before the plot is generated, you can interactively modify any of these values. A menu containing 15 items is displayed and you select those you wish to modify. When satisfied with the selections, enter a "-1" (the default value, selected by pressing the RETURN key) to generate the plot. You then return to the menu at which time you can modify other plot variables.[121] Enter a "0" to terminate the program.

The following information appears on your computer screen when G50_2T_DEMO is run:

```
ERAG50.  PLOT MODE SHAPES (WIREFRAME MODEL) USING TAPE88 (.UNV FILES)

HOW WILL GEOMETRY (COORDINATES) INFORMATION BE SUPPLIED ?  (1)
 1. GEOMETRY ASCII FILE
 2. .UNV FILE (TYPE 15 -SINGLE PRECISION OR TYPE 781 -DOUBLE PRECISION)
          1

NAME OF GEOMETRY ASCII FILE ?  [DEFAULT FILE TYPE = .DAT]
ERA$MMST_NAS:MMST_GEO.DAT


NO. OF GEOMETRY PTS =     54

HOW WILL CONNECTIVITY INFORMATION BE SUPPLIED ?  (1)
 1. CONNECTIVITY ASCII FILE
 2. .UNV FILE (TYPE 82 -TRACE LINES OR TYPE 780 -ELEMENTS)
          1

NAME OF CONNECTIVITY ASCII FILE ?  [DEFAULT FILE TYPE = .DAT]
ERA$MMST_NAS:MMST_CON.DAT


NO. OF CONNECTIVITY LINES =     126
```

[121]NOTE: If you answer 1=YES to the final question posed by program ERAG50, "Include a plot description on each plot? 1=yes", and you include these plot descriptions at the end of the GO Input file (as in this example), you will receive a fatal error if you attempt to plot additional modes because the program attempts to read additional plot descriptions from the GO Input file. This is avoided by changing plot variable No. 15 ("Include Plot Description on Each Plot? 1=Yes") to 0, or by including additional plot descriptions at the end of the GO Input file.

```
MODE SHAPE .UNV FILENAME ?  ENTER 'NONE' FOR UNDEFORMED SHAPE ONLY.
[DEFAULT FILE TYPE = .UNV])
88INIT_20_50.UNV


ROTATE MODE SHAPES TO BEST FIT NEAR +/-90 DEG BEFORE
DISPLAY FORMAT (NEXT QUESTION) IS APPLIED ? 1=YES  (1)
          1

DESIRED DISPLAY FORMAT ?  (1)
 1 = MAGNITUDE WITH SIGN OF IMAG. PART
 2 = REAL PART
 3 = IMAG. PART
          1

PLOT UNDEFORMED SHAPE USING ?  (3)
 0. NONE
 1. SOLID LINE
 2. LONG DASH
 3. SHORT DASH
          3

MAX. DEFLECTION IN % OF MAX. DIMENSION OF STRUCTURE?
 (10.0)
  10.00000

ALIGN WHICH OF THE STRUCTURE'S AXES WITH THE +Y AXIS OF THE DISPLAY ?  (1)
 1 = +X AXIS
-1 = -X AXIS
 2 = +Y AXIS
-2 = -Y AXIS
 3 = +Z AXIS
-3 = -Z AXIS
          2

ENTER X,Y,Z VIEWING POSITION
 -1.000000       1.000000      -1.000000

PLOT ROTATION ANGLE (CCW) IN DEGREES ?  (0.0)
 0.0000000E+00

PLOT SIZE ? [FULL SIZE = 1.00]  (0.95)
 0.9500000

CHARACTER SIZE (HT.) FOR PLOT LABELS, IN CM ?  (0.3)
 0.3000000

POINT NUMBERING ?  (1)
 0 = OFF
 1 = ALL PTS.
 2 = ONLY PTS. LISTED IN FILE NUM_POINTS.DAT
          0
```

```
DESIRED REFERENCE PT. ?  (1)
 [REF. POINT & DIRECTION WILL BE PLOTTED W/ POSITIVE SENSE]
         51

REFERENCE DIRECTION ? 1=X,-1=-X,2=Y,-2=-Y,3=Z,-3=-Z  (1)
NES? 1 = TURNED ON, 0 = TURNED OFF. (1)
          0

LENGTH OF TRIADE LEGS IN CM ?  (1.0)
  1.000000

X,Y ORIGIN OF TRIADE IN CM FROM DISPLAY LOWER-LEFT CORNER ?
  20.00000       3.000000

FIRST,LAST & STEP EIGENVALUE NOS. TO PLOT ?
          2           2           1

INCLUDE A PLOT DESCRIPTION ON EACH PLOT ? 1=YES (1)
          1

FROM WHERE SHOULD PLOT DESCRIPTIONS BE READ ?  (1)
 1. FROM GO INPUT FILE
 2. FROM KEYBOARD (INTERACTIVELY)
          1

GRAPHICS DEVICE NUMBER ?  (4)
  1 = TEK. 4010
  2 = TEK. 4014
  3 = TEK. 4025
  4 = TEK. 4107
  5 = TEK. 4115B
  6 = HP 2647/2648
  7 = DEC VT240
  8 = HPGL TALL
  9 = HPGL WIDE
 10 = POSTSCRIPT TALL
 11 = POSTSCRIPT WIDE


          4

CHOOSE ONE:  (-1)

-1. PLOT WITH CURRENT PARAMETERS
 0. END

 1. EIGENVALUE NOS. TO PLOT (FIRST,LAST,STEP):            2    2    1
    MODE SHAPE FILE: 88INIT_20_50.UNV
 2. STRUCTURE AXIS ALIGNED W/ DISPLAY Y-AXIS, 1=X,2=Y,3=Z (+/- OK): 2
 3. VIEWING POSITION (X,Y,Z EYE LOCATION):          -1.0   1.0  -1.0
 4. ROTATE MODE SHAPES TO ALIGN BEST W/ +/- 90 DEG? 1=YES:          1
 5. MODE SHAPE FORMAT TO PLOT (1=AMPL,2=REAL PART,3=IMAG. PART):    1
 6. PLOT SIZE (FULL SIZE = 1.00):                              0.950
 7. DEFLECTION AS % OF MAX. DIMENSION:                          10.0
```

```
 8. ROTATION ANGLE (CCW) IN DEG. ABOUT LINE-OF-SIGHT:                0.0
 9. POINT NUMBERING? 0=OFF,1=ALL PTS,2=PTS IN FILE NUM_POINTS.DAT:   0
10. CHARACTER SIZE IN CM:                                          0.300
11. UNDEFORMED SHAPE: 0=NONE,1=SOLID LINE,2=LONG DASH,3=SHORT DASH: 3
12. REF. PT & DIRECTION [PLOTTED W/ POSITIVE SENSE]:              51  2
13. TRIADE LEG LENGTH IN CM:                                        1.0
    TRIADE (X,Y) ORIGIN IN CM:                            20.0      3.0
14. TURN GRID LINES ON OR OFF. 1=ON:                                0
15. INCLUDE PLOT DESCRIPTION ON EACH PLOT? 1=YES:                   1

         -1

PLOTTING MODE SHAPE RECORD   2
WARNING: MODE SHAPE FILE CONTAINS DATA FOR UNKNOWN LOCATION NO.     201
WARNING: MODE SHAPE FILE CONTAINS DATA FOR UNKNOWN LOCATION NO.     203

ENTER DESCRIPTION FOR MODE SHAPE NO.   2
2ND TORSION MODE
```

Two warning messages occur because mode shape data for location numbers 201 and 203 exist in the Tape88 .UNV file but do not exist in the model geometry file. These location numbers are fictitious values added to designate driving point measurements for Shakers 1 and 3. Shakers 1 and 3 are oriented in skewed directions. Driving point measurements for these shakers are assigned the artificial coordinate codes of 201Z and 203Z, respectively. Shaker 2 is oriented in the global Y direction at geometry location 23. It is identified as measurement 23Y.

Program ERAG50 reads geometry information from either simple ASCII files (FORTRAN free-field format) or from Type 15 (single precision) or Type 781 (double precision) Universal files. Connectivity information is read from either simple ASCII files (FORTRAN free-field format) or from Type 82 (trace lines) or Type 780 (elements) Universal files. The GO Input file named G50_2T_DEMO.COM discussed above that generates Fig. 3-10 uses simple ASCII geometry and connectivity files named ERA$MMST_NAS:MMST_GEO.DAT and ERA$MMST_NAS:MMST_CON.DAT, respectively.

A sample GO Input file that uses geometry and connectivity Universal files instead of simple ASCII files is also available. It is file ERA$GO:G50UNV_2T_DEMO.COM. Geometry and connectivity data are read from files ERA$MMST_NAS:MMST_GEO.UNV and ERA$MMST_NAS:MMST_CON.UNV, respectively. The SDRC TDAS program wrote these Universal files. Execution of file G50UNV_2T_DEMO.COM (using GO) generates the same plot as in Fig. 3-10.

Here is a listing of the ASCII geometry file (ERA$MMST_NAS:MMST_GEO.DAT) used by GO Input file G50_2T_DEMO.COM:

```
     1    0.0000    0.7000    2.2400
```

2	0.6062	-0.3500	2.2400
3	-0.6062	-0.3500	2.2400
4	0.0000	0.7000	3.3600
5	0.6062	-0.3500	3.3600
6	-0.6062	-0.3500	3.3600
7	0.0000	0.7000	4.4800
8	0.6062	-0.3500	4.4800
9	-0.6062	-0.3500	4.4800
10	0.0000	0.7000	5.6000
11	0.6062	-0.3500	5.6000
12	-0.6062	-0.3500	5.6000
13	0.0000	0.7000	6.7200
14	0.6062	-0.3500	6.7200
15	-0.6062	-0.3500	6.7200
16	0.0000	0.7000	7.8400
17	0.6062	-0.3500	7.8400
18	-0.6062	-0.3500	7.8400
19	0.0000	0.7000	8.9600
20	0.6062	-0.3500	8.9600
21	-0.6062	-0.3500	8.9600
22	0.0000	0.7000	10.0800
23	0.6062	-0.3500	10.0800
24	-0.6062	-0.3500	10.0800
25	0.0000	0.7000	11.2000
26	0.6062	-0.3500	11.2000
27	-0.6062	-0.3500	11.2000
28	0.0000	0.7000	12.3200
29	0.6062	-0.3500	12.3200
30	-0.6062	-0.3500	12.3200
31	0.0000	0.7000	13.4400
32	0.6062	-0.3500	13.4400
33	-0.6062	-0.3500	13.4400
34	0.0000	0.7000	14.5600
35	0.6062	-0.3500	14.5600
36	-0.6062	-0.3500	14.5600
37	0.0000	0.7000	15.6800
38	0.6062	-0.3500	15.6800
39	-0.6062	-0.3500	15.6800
40	0.0000	0.7000	16.8000
41	0.6062	-0.3500	16.8000
42	-0.6062	-0.3500	16.8000
43	0.0000	0.7000	17.9200
44	0.6062	-0.3500	17.9200
45	-0.6062	-0.3500	17.9200
46	0.0000	0.7000	19.0400
47	0.6062	-0.3500	19.0400
48	-0.6062	-0.3500	19.0400
49	0.0000	0.7000	20.1600
50	0.6062	-0.3500	20.1600
51	-0.6062	-0.3500	20.1600
101	0.0000	0.7000	0.0000
102	0.6062	-0.3500	0.0000
103	-0.6062	-0.3500	0.0000

Each line of this file contains a measurement point number (grid point number) followed by the global Cartesian coordinates (X, Y, Z) of the point. The entries on each line can be separated by commas or by one or more spaces (FORTRAN free-field format). All entries must be given in global Cartesian coordinates, and there is no capability to use local coordinate systems for various components. The coordinates can use any consistent set of units. In this example, the coordinates are given in meters. The measurement point numbers can appear in any numerical order.

The last 3 point numbers in this listing, 101, 102, 103, are at the clamped base position of Mini-Mast. There are no response measurements at these locations and thus there are no corresponding mode-shape entries in the Tape88 .UNV file. Thus, these locations always appear stationary (clamped) in deformed-geometry plots. Similarly, any other degrees-of-freedom appearing in the geometric shape but not occurring in the mode shape file (such as all of the Z-direction degrees-of-freedom in this example) will also appear stationary in the deformed-geometry plots.

Here is a listing of the ASCII connectivity file used by GO Input file G50_2T_DEMO.COM. It is named ERA$MMST_NAS:MMST_CON.DAT. Program ERAG50 uses this information for connecting the measurement points by straight lines. A line is drawn between each successive point listed in the file. The numbers on each line of the file can be separated by commas or by one or more spaces (FORTRAN free-field format), and you can place any number of values on each line. A negative number causes the "pen" to be moved to the indicated point without drawing a line.

```
101     1     4     7    10    13    16    19
 22    25    28    31    34    37    40    43
 46    49  -102     2     5     8    11    14
 17    20    23    26    29    32    35    38
 41    44    47    50  -103     3     6     9
 12    15    18    21    24    27    30    33
 36    39    42    45    48    51  -101   102
103   101    -1     2     3     1    -4     5
  6     4    -7     8     9     7   -10    11
 12    10   -13    14    15    13   -16    17
 18    16   -19    20    21    19   -22    23
 24    22   -25    26    27    25   -28    29
 30    28   -31    32    33    31   -34    35
 36    34   -37    38    39    37   -40    41
 42    40   -43    44    45    43   -46    47
 48    46   -49    50    51    49
```

3.9.4 Undeformed Wireframe Plots (ERAG50)

The undeformed geometry of the structure (alone) can also be plotted using program ERAG50 by entering "NONE" for the name of the Tape88 input file. Measurement numbers appear by answering "1=yes" to the "Turn On Point Numbering?" question (Question No. 9) asked by ERAG50. **Fig. 3-11** shows an example plot.

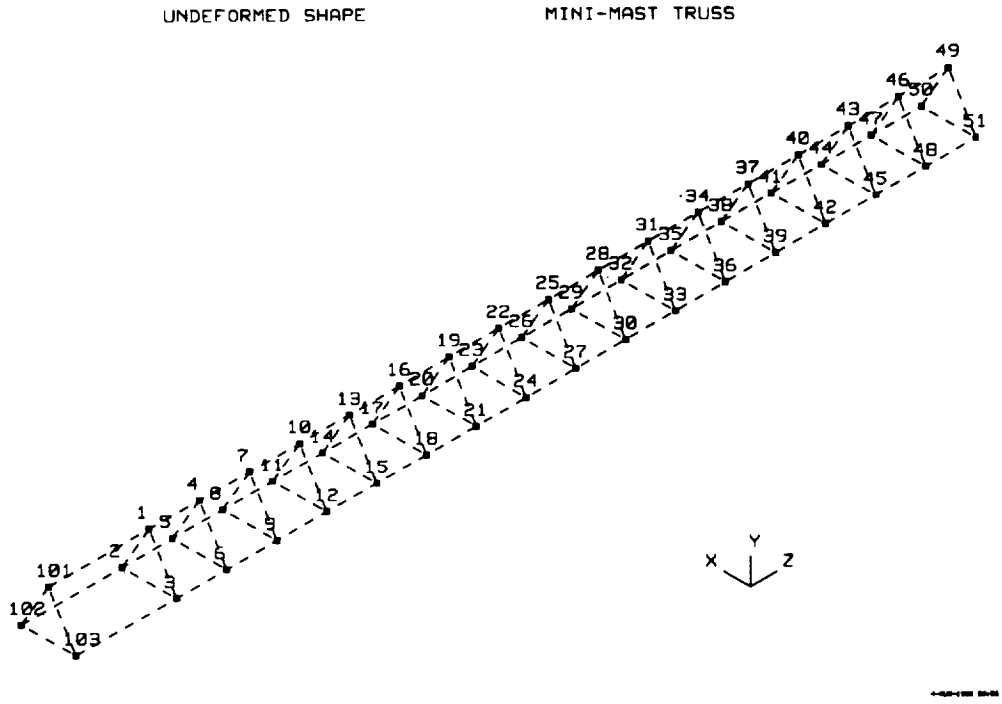


Fig. 3-11. Undeformed Shape With Numbered Measurement Locations [G50_UNDEFORMED_DEMO]

Fig. 3-11 is generated using GO Input file G50_UNDEFORMED_DEMO.COM. Copy this file into your current default directory and execute it as follows:

```
COPY ERA$GO:G50_UNDEFORMED_DEMO.COM []

GO G50_UNDEFORMED_DEMO
```

Here is a listing of file G50_UNDEFORMED_DEMO.COM:

```
$! G50_UNDEFORMED_DEMO.COM
$!
$ RUN ERA$EXES:ERAG50
1   TYPE OF GEOMETRY FILE: 1=ASCII FILE, 2=.UNV FILE
ERA$MMST_NAS:MMST_GEO.DAT      GEOMETRY FILE NAME
1   TYPE OF CONNECTIVITY FILE: 1=ASCII FILE, 2=.UNV FILE
ERA$MMST_NAS:MMST_CON.DAT      CONNECTIVITY FILE NAME
NONE                    TAPE88 FILE. 'NONE' = STATIC PLOT
1 ROTATE MODES TO +/-90 DEG. BEFORE ANSWERING NEXT QUESTION)? 1=YES
```

```
1         DISPLAY FORMAT: 1=AMPLITUDE, 2=REAL PART, 3=IMAG. PART
3         UNDEFORMED SHAPE AS: 1=SOLID LINE, 2=LONG DASH, 3=SHORT DASH
10.0      MAX. DEFLECTION AS PERCENT OF MAX. DIMENSION OF STRUCTURE
2         STRUCTURE'S AXIS TO ALIGN W/ Y-AXIS OF DISPLAY (1=X, 2=Y, 3=Z)
-1,1,-1   VIEWING LOCATION (X,Y,Z)
0         PLOT ROTATION ANGLE IN DEGREES
0.95      PLOT SIZE.  FULL SIZE = 1.0
0.3       CHARACTER SIZE IN CM
1         TURN ON POINT NUMBERING?  1=YES
100       NUMBER SIZE AS % OF CHARACTER SIZE
-100      X DISTANCE IN % OF NUMBER SIZE FROM PT. TO LL CORNER OF NUMBER
100       Y DISTANCE IN % OF NUMBER SIZE FROM PT. TO LL CORNER OF NUMBER
51        DESIRED REFERENCE PT.
2         REFERENCE DIRECTION
0         GRID LINES ON? 1=YES
1         LENGTH OF ORIENTATION TRIADE LEGS IN STRUCTURAL ENG. UNITS
20,3      TRIADE ORIGIN (X,Y) IN CM FROM LOWER-LEFT CORNER OF DISPLAY
2,2,1     FIRST,LAST,STEP EIGENVALUES TO PLOT?  ENTER 0,0,0 TO END
1         WRITE DESCRIPTION ON EACH PLOT? 1=YES
1         WHERE TO READ DESCRIPTION FROM? 1=GO INPUT FILE, 2=KEYBOARD
MINI-MAST TRUSS
```

The information in this GO Input file establishes initial values for various program variables. Before the plot is generated, however, you can interactively modify any of these values. A menu containing 15 variables is displayed and you select those you wish to modify. When satisfied with the selections, enter a "-1" (default value, selected by pressing the RETURN key) to generate the plot. You then return to the menu at which time you can modify other plot variables.[122] Entering a "0" terminates the program.

3.10 Looping Option 1 (No. of Retained Singular Values)

Experience has shown that significant changes can occur in ERA results as a function of the assumed number of modes.[123] Optimum accuracy for different modes typically occurs at different numbers of assumed modes. Also, weakly excited modes often require relatively high numbers of assumed modes to be properly identified. For these reasons, the assumed number of modes is normally incremented over a wide range of values in practice.

---

[122]NOTE: If you answer 1=YES to the final question posed by program ERAG50, "Include a plot description on each plot? 1=yes", and you include these plot descriptions at the end of the GO Input file (as in this example), you will receive a fatal error if you attempt to plot additional modes because the program attempts to read additional plot descriptions from the GO Input file. This is avoided by changing plot variable No. 15 ("Include Plot Description on Each Plot? 1=Yes") to 0, or by including additional plot descriptions at the end of the GO Input file.

[123]Large changes in the results often occur for some modes with experimental data. With simulated data, on the other hand, the changes are typically much smaller or negligible.

Various analysis parameters are incremented automatically using parameter LOOPOP. LOOPOP is an acronym for "looping option." Setting LOOPOP equal to 1 causes the number of retained singular values to be incremented. The number of retained singular values equals the size (order) of the eigenvalue problem that is solved. Because modes of vibration correspond to complex-conjugate pairs of eigenvalues, **the assumed number of modes equals one-half the number of retained singular values.** Any particular number of retained singular values is selected using parameter IORDTU, which is an acronym for "order to use." To increment parameter IORDTU automatically over a range of values, set LOOPOP equal to 1, then specify the desired first, last, and delta values of IORDTU with (array) variable PAR.[124] For example, IORDTU is incremented automatically from 10 to 100 in steps of 5 by including the following statement in Field 4 of the User Input file:[125]

```
LOOPOP=1,PAR=10,100,5
```

Identification results are presented below for the analysis of the 20 - 50 Hz data. The number of retained singular values is incremented from 2 to 80 in steps of 2, corresponding to an assumed number of modes ranging from 1 to 40. The maximum number of retained singular values always equals MIN(MCH,MRH) which is 81 in this example. The User Input file for this analysis is INIT_20_50_LOOPOP1.ERA, stored in directory ERA$MMST_NAS. Here is a listing of this file:

```
$! INIT_20_50_LOOPOP1.ERA
$!
$! INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  [PAPPA.DEMO]
$ DEFINE ERA_OUTPUT$ [PAPPA.DEMO]
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=INIT_20_50_LOOPOP1
$!
$ INPUT1:=_MMST_NAS_SH1_20_50
$ INPUT2:=_MMST_NAS_SH2_20_50
```

[124]The syntax of the 3 variables specified by PAR() is the same as that of a traditional FORTRAN DO-LOOP statement.

[125]Note that odd values of IORDTU are permitted; e.g. 10, **15**, 20, **25**, 30, **35**, ... as in this example. IORDTU equal to 15 corresponds to "7-1/2" assumed modes. With this selection, the ERA analysis will identify 7 (or less) complex-conjugate pairs of eigenvalues and 1 (or more) real eigenvalues. The total number of identified eigenvalues, counting each complex-conjugate pair as 2 eigenvalues, always equals IORDTU.

```
$ INPUT3:=_MMST_NAS_SH3_20_50
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                        MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                        MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                        MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                        MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=81/
S/MRH=/MRH=520/
S/MIC=/MIC=3/
S/MST=/MST=104/
S/MTIM=/MTIM=1920/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=60.,FMIN=20.
  LOOPOP=1,PAR=2,80,2
  ITAPE(50)=0,ITAPES=88
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!             [ALWAYS USE EXACTLY 5 LINES]
$!
 LINE 1 FOR COMMENTS
 INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
 FILTERED DATA: 20 - 50 HZ
 NO. ASSUMED MODES = 1,40,1 (RETAINED SV'S = 2,80,2)
 INIT_20_50_LOOPOP1:
```

This job is identical to the initial analysis of simulated data discussed in Section 3.5 (Job INIT_20_50) except that the analysis parameters (Field 4 of the User Input file) are slightly different. The 2 lines highlighted in bold type are new. The statement

```
LOOPOP=1,PAR=2,80,2
```

specifies that parameter IORDTU (the "order to use" = the number of retained singular values) is to be incremented from 2 to 80 in steps of 2. This selection corresponds to 1 to 40 assumed modes. The statement

```
ITAPE(50)=0
```

deactivates the Tape50 output file. In looping analyses, Tape50 can become excessively large and is normally deactivated. The statement

```
ITAPES=88
```

activates the Tape88 output file. Tape88 contains the identified mode shapes in Universal File format.

If you wish to continue following along on your computer, you must now run this ERA job. It is normally executed as a batch job because of its size. Copy the User Input file into your default directory and execute it as follows:

```
COPY ERA$MMST_NAS:INIT_20_50_LOOPOP1.ERA []

ERA INIT_20_50_LOOPOP1
```

This ERA analysis required approximately 49 minutes of CPU time on the author's VAXstation 3100 computer.

The results of looping analyses are normally read from the Tape85 output file. This file is activated by default and contains a "1-line-per-eigenvalue" summary of the results. Program ERAG15 plots these results. GO Input File named G15F_20_50_DEMO.COM plots the identified natural frequencies of Job INIT_20_50_LOOPOP1. The "F" in this filename signifies that only frequencies are to be plotted. Here is a listing of file G15F_20_50_DEMO.COM:

```
$! G15F_20_50_DEMO.COM
$!
$ RUN ERA$EXES:ERAG15
85INIT_20_50_LOOPOP1      TAPE85 FILE NAME
1       FIRST CASE TO PLOT
40      LAST CASE TO PLOT
1       DELTA FOR Y-AXIS MINOR TIC MARKS  (0.0 = NONE)
20      FMIN TO PLOT
50      FMAX TO PLOT
1       DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS  (0.0 = NONE)
1       NO. OF PLOTS
4       ACCURACY INDICATOR TO USE AS CUT-OFF?  1=EMAC, 2=MPC-W, 3=MPC-U, 4=CMI
1       MINIMUM ACCURACY INDICATOR VALUE (%) TO INCLUDE?
1       USE DEFAULT Y-AXIS LABEL (BASED ON THE VALUE OF IOPT)?  1=YES
0.4     CHARACTER SIZE IN CM
1       FONT TYPE
0       Y-AXIS GRID LINES?  1=YES
0       ADD ADDITIONAL DOTTED VERTICAL LINES?  1=YES
0       SAVE (FREQ,ACCURACY INDICATOR) RESULTS IN A FILE?  1=YES
1       USE DEFAULT OVERALL WINDOW SIZE?  1=YES
0       MODIFY DEFAULT AXIS NUMBERS?  1=YES
```

Copy files G15F_20_50_DEMO.COM, G15_OPTIONS_DEMO.COM, and FREQS_AND_DAMPS.DAT into your working directory as follows:

```
COPY ERA$GO:G15F_20_50_DEMO.COM []

COPY ERA$OPTIONS:G15_OPTIONS_DEMO.DAT G15_OPTIONS.DAT

COPY ERA$MMST_NAS:FREQS_AND_DAMPS.DAT []
```

File G15_OPTIONS_DEMO.DAT activates the MARKFD=1 hidden option (ref. Section 8.3) that plots triangles at the top of ERAG15 figures at the frequencies (and assumed damping values) of NASTRAN modes. MARKFD is an acronym for "mark frequency and damping values." Note that G15_OPTIONS_DEMO.DAT is renamed to G15_OPTIONS.DAT when it is copied. Here are the contents of this file:

```
$G15_OPTIONS
MARKFD=1,TFDNAM='FREQS_AND_DAMPS.DAT'
$END
```

File FREQS_AND_DAMPS.DAT is an ASCII file containing the NASTRAN frequencies (Hz) and assumed damping factors (%). Here are the 13 modes between 20 and 50 Hz. The complete file contains data for all 153 NASTRAN modes (ref. Section 12.13).

```
117        20.3080006        1.0000000
118        21.5699997        1.0000000
119        23.4740009        1.0000000
120        28.6480007        1.0000000
121        30.7210007        1.0000000
122        32.0639992        1.0000000
123        37.3349991        1.0000000
124        38.3089981        1.0000000
125        38.3219986        1.0000000
126        38.3219986        1.0000000
127        39.0120010        1.0000000
128        42.2220001        1.0000000
129        44.8559990        1.0000000
```

Execute file G15F_20_50_DEMO.COM in the usual manner using GO as follows:

```
GO G15F_20_50_DEMO
```

The following information appears on your computer screen when G15F_20_50_DEMO.COM is run:

```
*** WARNING.  HIDDEN OPTIONS READ IN FROM FILE G15_OPTIONS:
$G15_OPTIONS
NUMMDS  =           0,
MARKFD  =           1,
TFDNAM  = 'FREQS_AND_DAMPS.DAT

NOTPLB  =           0,
IBORDR  =           0,
NFWNDS  =           1
$END

O.K. TO CONTINUE ?  1=YES  (1)
```

```
          1

ERAG15.  PLOT TAPE85 DATA VS. CASE NO. (4 PLOTS/PAGE MAX.)

TAPE85 FILENAME ?  [DEFAULT FILE TYPE = .LIS]
85INIT_20_50_LOOPOP1.LIS


MARKFD=1.  FILE NAME CONTAINING MODE NOS., FREQS. AND DAMPING FACTORS
(3 COLS) FOR FREQS. AND ZETAS TO MARK AT TOP OF PLOT USING
INVERTED TRIANGLES:
FREQS_AND_DAMPS.DAT

  153 FREQS. AND ZETAPS TO BE MARKED AT TOP OF PLOT
USING INVERTED TRIANGLES

FIRST CASE NO. TO PLOT ?  (1)
          1

LAST CASE NO. TO PLOT ?  (75)
         40

DELTA FOR Y-AXIS MINOR TIC MARKS ? 0=NONE  (2)
  1.000000

LOWEST FREQUENCY TO PLOT ?  (0.0)
  20.00000

HIGHEST FREQUENCY TO PLOT ?  (256.0)
  50.00000

DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS ? 0=NONE  (1.0)
  1.000000

NO. OF PLOTS DESIRED ? [MAX.=8]  (8)
          1

WHICH ACCURACY INDICATOR TO USE (AS CUT-OFF CRITERION) ?  (1)
 1. EMAC  (EXTENDED MODAL AMPLITUDE COHERENCE)
 2. MPC-W (WEIGHTED MODAL PHASE COLLINEARITY)
 3. MPC-U (UNWEIGHTED MODAL PHASE COLLINEARITY)
 4. CMI = EMAC * MPC-W (CONSISTENT MODE INDICATOR)
99. NONE.  PLOT ALL FREQ. LINES FULL HEIGHT
          4

MINIMUM CMI (%) TO INCLUDE ?  (30.0)
  1.000000

LOOPOP =   1
PAR() =     2.000    80.000     2.000  -999.000  -999.000

USE DEFAULT Y-AXIS LABEL (SELECTED BASED ON LOOPOP) ?  1=YES (1)
          1
```

```
THE FOLLOWING Y-AXIS LABEL WILL BE USED:
  ASSUMED NO. OF MODES

CHARACTER SIZE (HT.) FOR PLOT LABELS, IN CM ?  (0.5)
 0.4000000

FONT TYPE ?  (1)
 1 = STICK FONT
 2 = LETTER QUALITY - BOLD
 3 = LETTER QUALITY - STD.
          1

INCLUDE X-AXIS GRID LINES (AT EACH TIC) ? 1=YES (0)
          0

ALSO ADD ADDITIONAL DOTTED VERTICAL LINES?  1=YES  (0)
          0

SAVE FREQUENCY/INDICATOR RESULTS IN A FILE
(2 COL. FORMAT) 1=YES  (0) ?
          0

USE THE DEFAULT OVERALL WINDOW SIZE ? 1=YES  (1)
          1

MODIFY DEFAULT AXIS NUMBERS ?  1=YES  (0)
          0

GRAPHICS DEVICE NUMBER ?  (4)
  1 = TEK. 4010
  2 = TEK. 4014
  3 = TEK. 4025
  4 = TEK. 4107
  5 = TEK. 4115B
  6 = HP 2647/2648
  7 = DEC VT240
  8 = HPGL TALL
  9 = HPGL WIDE
 10 = POSTSCRIPT TALL
 11 = POSTSCRIPT WIDE
```

Fig. 3-12 shows the resulting plot.

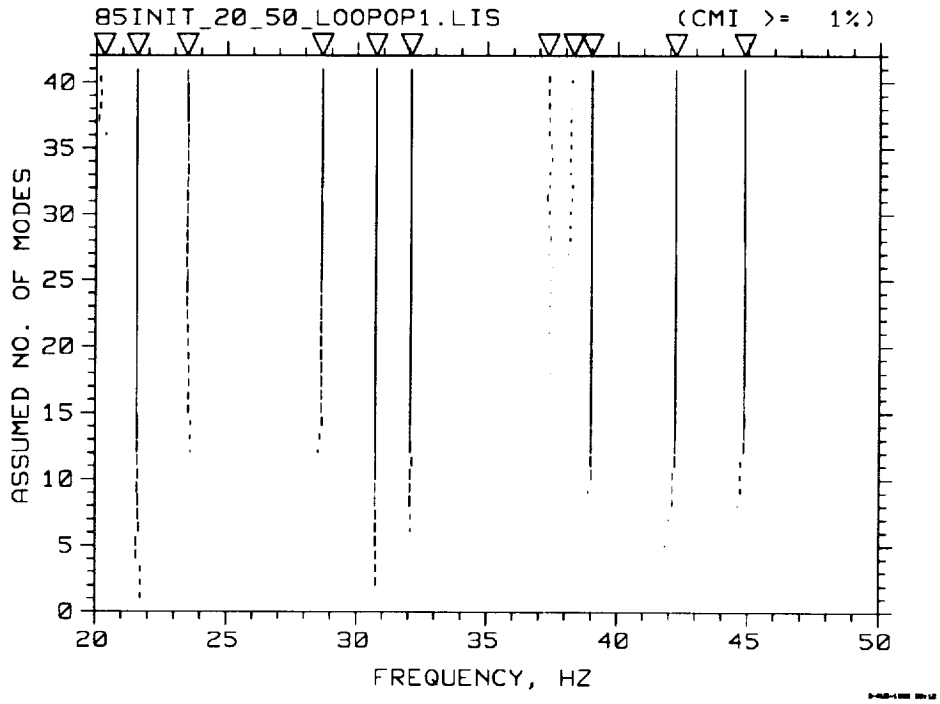


Fig. 3-12. Identified Natural Frequencies vs Assumed No. of Modes, with Lengths of Vertical Dashes Proportional to CMI [G15F_20_50_DEMO]

Each row of results in this plot corresponds to a separate ERA analysis with a specified number of assumed modes. Each identified mode is indicated by a vertical dash at the associated frequency. The confidence in each result is expressed by the length of the vertical dash which is proportional to the Consistent-Mode Indicator, CMI (Ref. 8 and Section 2.6.1). The highest confidence (CMI = 100%) corresponds to a vertical dash height equal to the distance between minor tic marks on the y axis. Eigenvalues with low CMI (less than 1 percent in this example) are excluded from the figure. This CMI cutoff value appears at the upper-right corner of the figure.

A wide spread of CMI values occurs in this example. This is typical of many analyses of experimental data. Although engineering judgment is necessary to determine the cause of low CMI values, low values reliably indicate those results that should not be accepted verbatim as accurate modal parameters. As discussed in Section 3.14 of this User's Guide, results for particular modes can often be improved using the "KEYDTA" feature of this software, once these initial identification results are available. Of course, additional tests may also improve certain results once areas of difficulty are known.

With program ERAG15, corresponding results for up to 7 additional parameters can be plotted. The following parameters are available:[126]

```
 2. DAMPING
 3. AMPLITUDE
 4. MPC-W
 5. MPC-U
 6. EMAC
 7. MODAL STRENGTH RATIO (MSR)
 8. CMI (CMI = EMAC * MPC-W)
 9. PHASE
10. ZETA2 (ALTERNATE DAMPING ESTIMATE)
11. PHASE RESONANCE CRITERION
12. MAC WITH A SPECIFIED NASTRAN MODE
13. RECIPROCITY
14. NO. OF RETAINED SINGULAR VALUES
```

The following examples use Damping Factor, Consistent-Mode Indicator (CMI), Zeta2, Extended Modal Amplitude Coherence (EMAC), Weighted Modal Phase Collinearity (MPC-W), Modal Strength Ratio (MSR), and Modal Assurance Criterion (MAC).

When plotting additional parameters with ERAG15, one mode at a time is normally isolated to simplify the resulting plot. As an example, **Figs. 3-13, 3-14, and 3-15** show 3 modes from Fig. 3-12 replotted in this manner. Fig. 3-13 is a strongly excited mode at 30.7 Hz, Fig. 3-14 is a moderately excited mode at 23.5 Hz, and Fig. 3-15 is a weakly excited mode at 37.3 Hz.[127] **These results illustrate the wide variation of identification accuracy typically obtained with complex data sets.**

GO Input files named G15_8_30P7_DEMO.COM, G15_8_23P5_DEMO.COM, and G15_8_37P3_DEMO.COM are available for this purpose. The "8" in these file names indicates that 8 parameters will be plotted. Here is a listing of file G15_8_30P7_DEMO.COM:

```
$! G15_8_30P7_DEMO.COM
$!
$ RUN ERA$EXES:ERAG15
85INIT_20_50_LOOPOP1      TAPE85
1           FIRST CASE TO PLOT
40          LAST CASE TO PLOT
2           DELTA FOR Y-AXIS MINOR TIC MARKS  (0.0 = NONE)
```

[126]Parameter No. 1 is missing from the list because the software assigns it to FREQUENCY, which always appears as the first plot.

[127]The relative strength of these 3 modes is readily apparent from Fig. 3-12: strongly excited modes have solid, straight lines beginning at low numbers of assumed modes, moderately excited modes have dashed lines beginning at higher numbers of assumed modes, and weakly excited modes have shifting, dotted (or dashed) lines beginning at high numbers of assumed modes.

```
30          FMIN TO PLOT
31          FMAX TO PLOT
.1          DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS  (0.0 = NONE)
8           NO. OF PLOTS PER PAGE?  MAX. = 8
1           PUT ALL PLOTS ON 1 PAGE(1) OR SEPARATE PAGES(2)
2 PLOT 2: 2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
0.0         MIN. PLOT VALUE
3.0         MAX. PLOT VALUE
0.1         DELTA PLOT VALUE
8 PLOT 3: 2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
0           MIN. PLOT VALUE
101         MAX. PLOT VALUE
10          DELTA PLOT VALUE
10 PLOT 4: 2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC
,12=MAC,13=RECIP
0.0         MIN. PLOT VALUE
3.0         MAX. PLOT VALUE
0.1         DELTA PLOT VALUE
6 PLOT 5: 2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
0           MIN. PLOT VALUE
101         MAX. PLOT VALUE
10          DELTA PLOT VALUE
4 PLOT 6: 2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
0           MIN. PLOT VALUE
101         MAX. PLOT VALUE
10          DELTA PLOT VALUE
7 PLOT 7: 2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
0           MIN. PLOT VALUE
50          MAX. PLOT VALUE
5           DELTA PLOT VALUE
12 PLOT 8:2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
0           MIN. PLOT VALUE
101         MAX. PLOT VALUE
10          DELTA PLOT VALUE
ERA$MMST_NAS:MMST_NASEIGV_900110_TESTDOFS.UNV    NASTRAN MODE SHAPE FILE
121         NASTRAN MODE TO CORRELATE WITH
            TAPE88 FILE?  DEFAULT = 88.. (OTHERWISE SAME AS TAPE85 NAME)
ERA$MMST_NAS:MMST.LOC      TEST-ANALYSIS MAPPING FILE
4           ACC. IND. TO USE AS CUT-OFF?  1=EMAC,2=MPC-W,3=MPC-U,4=CMI,99=NONE
1           MINIMUM ACCURACY INDICATOR VALUE (%) TO INCLUDE?
1           USE DEFAULT Y-AXIS LABEL (BASED ON THE VALUE OF IOPT)?  1=YES
0.25        CHARACTER SIZE IN CM
1           FONT TYPE. 1=STICK
0           X-AXIS GRID LINES?  1=YES
0           ADD ADDITIONAL DOTTED VERTICAL LINES?  1=YES
1           CHAR. SIZE FOR NUMBERS IN PLOTS 2+.   1=STD
0           SAVE FREQ./INDICATOR RESULTS IN A FILE?  1=YES
1           USE DEFAULT OVERALL WINDOW SIZE?  1=YES
```

```
0            MODIFY DEFAULT AXIS NUMBERS?  1=YES
```

Copy this file into your current default directory and execute it as follows:[128]

```
COPY ERA$GO:G15_8_30P7_DEMO.COM []

GO G15_8_30P7_DEMO
```

Execute the other 2 GO Input files similarly.

The lower-right plot in these figures shows the Modal Assurance Criterion (MAC) between the ERA-identified mode shapes and the corresponding NASTRAN mode shape. The appropriate NASTRAN mode number is specified in the GO Input file. Section 12.13 provides these NASTRAN mode numbers.

[128]You also need file G15_OPTIONS.DAT in your working directory. This "hidden options" file was copied from directory ERA$OPTIONS (file G15_OPTIONS_DEMO.DAT) when Fig. 3-12 was plotted.

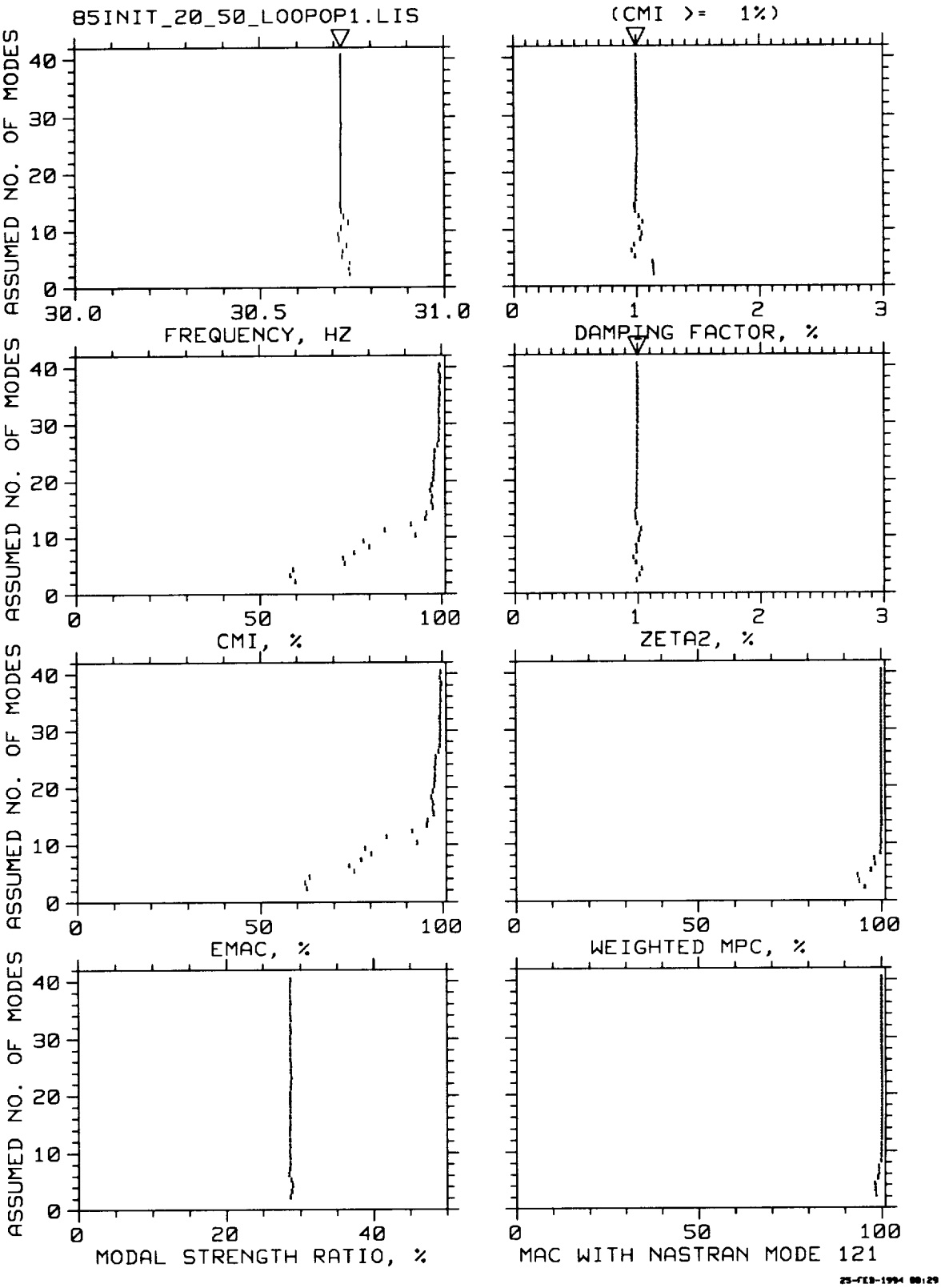


Fig. 3-13. Identification Results For Strongly Excited Mode at 30.7 Hz [G15_8_30P7_DEMO]

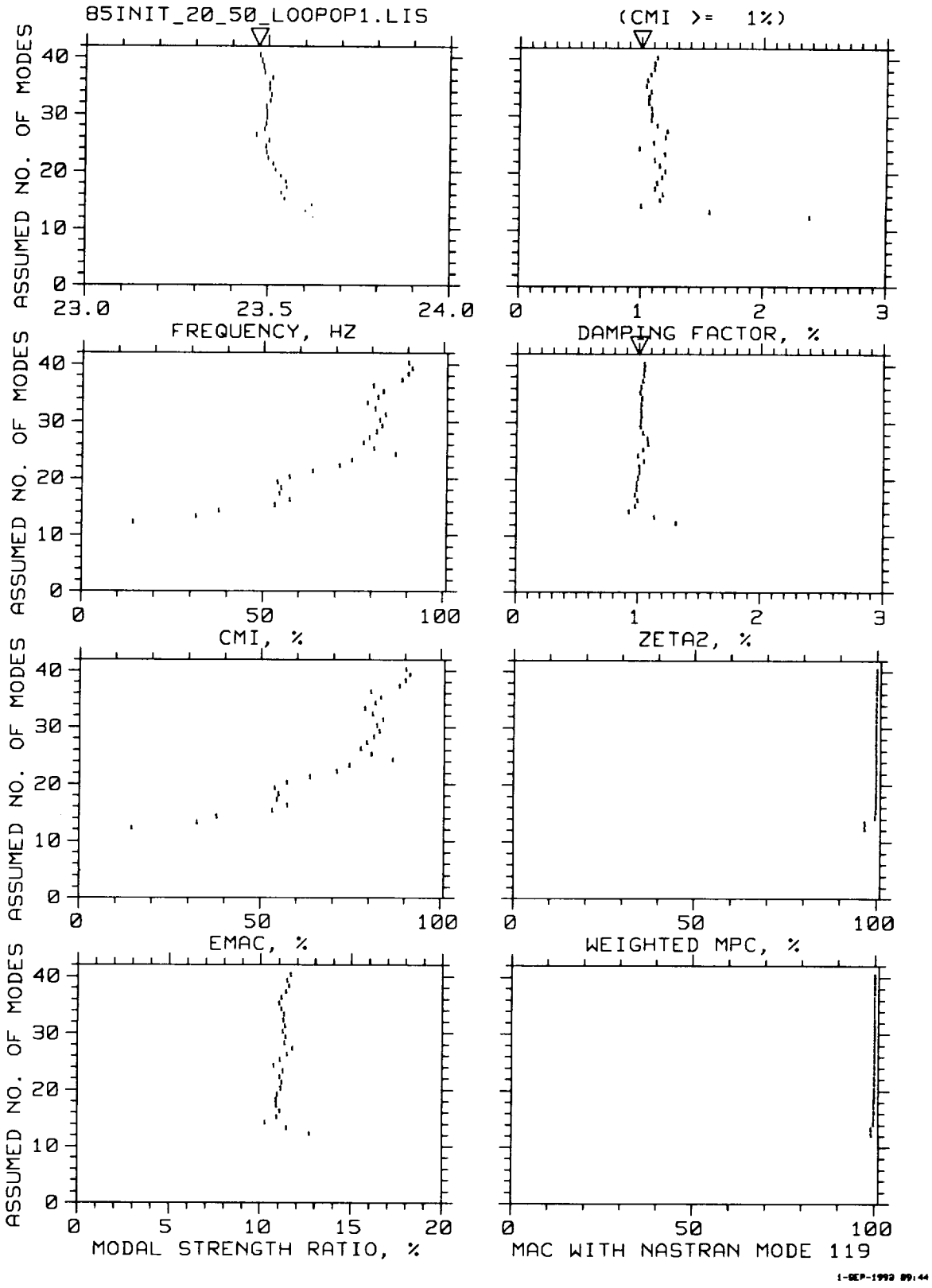


Fig. 3-14. Identification Results For Moderately Excited Mode at 23.5 Hz [G15_8_23P5_DEMO]

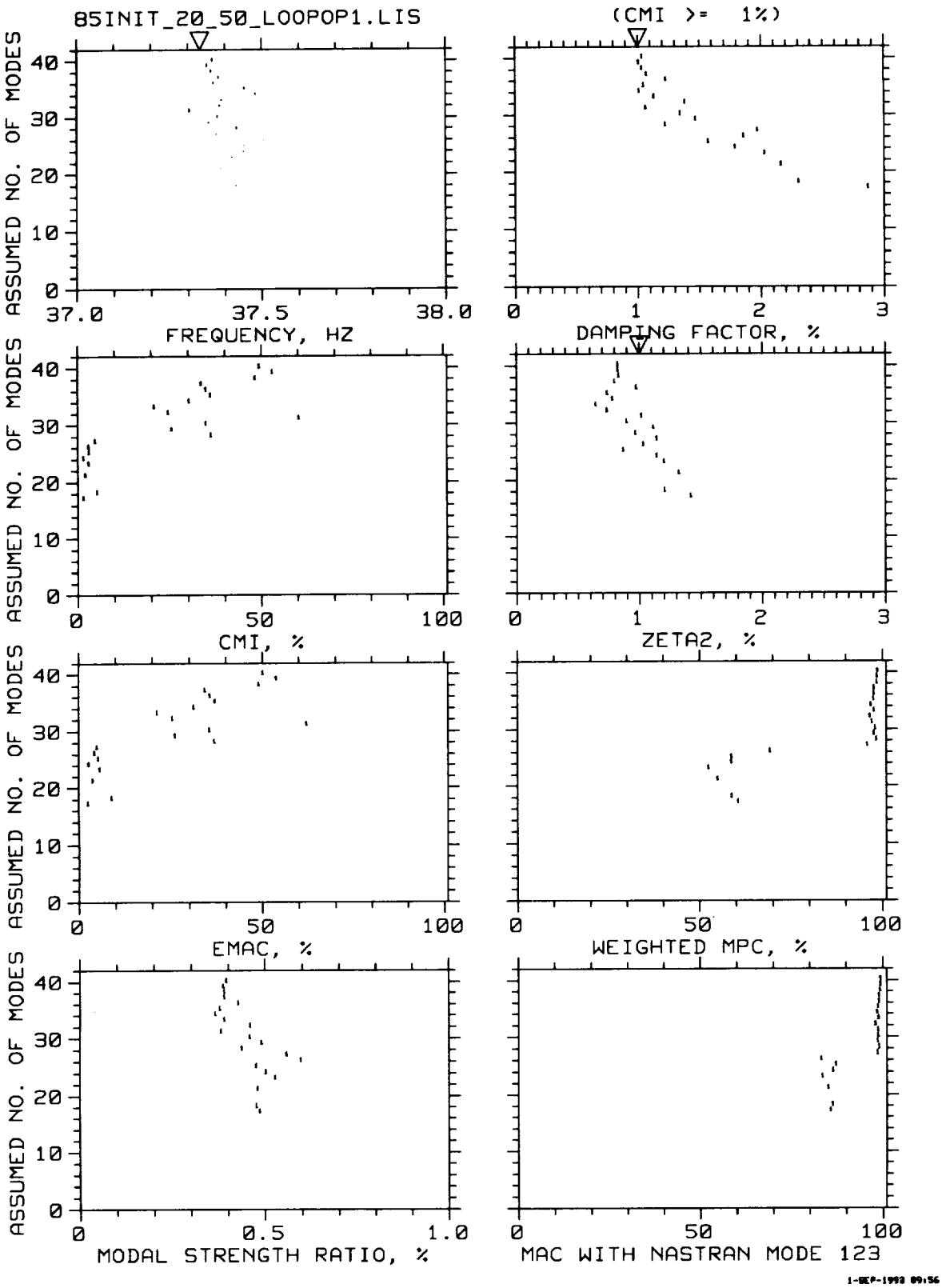


Fig. 3-15. Identification Results For Weakly Excited Mode at 37.3 Hz [G15_8_37P3_DEMO]

3.11 Looping Option 2 (Sliding Time Window)

ERA assumes linearity, yet in practice all mechanical systems are nonlinear to some extent. If the degree of nonlinearity is small, ERA can be applied with little difficulty. If the degree of nonlinearity is large, however, piecewise linear analysis is necessary. That is, small time segments of data must be analyzed separately and the results compared to identify changes in eigenvalues and eigenvectors as a function of response amplitude.

With linear data, identification accuracy improves as the analysis time window (NTIM) is lengthened due to the least squares effect.[129] With nonlinear data, however, longer time windows can cause undesirable behavior such as "pole splitting," i.e., identification of 2 or more closely spaced eigenvalues where only 1 eigenvalue actually exists due to varying eigenproperties as a function of response amplitude. **Piecewise ERA analysis using a sliding time window is normally performed on all experimental data sets to assess the degree of nonlinearity and to quantify eigenparameter variation, on a mode-by-mode basis.**

User parameter NSKIP is the number of time samples skipped at the beginning of each Tape1 data record. (The default value of NSKIP is 0.) NSKIP can be incremented over a range of values by specifying LOOPOP=2 in Field 4 of the ERA User Input file. LOOPOP is an acronym for "Looping Option." This generates a "sliding time window" analysis. The first, last, and delta values of NSKIP are specified with (array) parameter PAR. For example, to increment NSKIP from 0 to 290 in steps of 10, include the following statement in the ERA User Input file:

```
LOOPOP=2,PAR=0,290,10
```

Now, perform an analysis of this type on the 20 to 50 Hz data set using ERA User Input file INIT_20_50_LOOPOP2. Here is a listing of this file:

```
$! INIT_20_50_LOOPOP2.ERA
$!
$! INITIAL ANALYSIS OF MINI-MAST DATA
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  [PAPPA.DEMO]
$ DEFINE ERA_OUTPUT$ [PAPPA.DEMO]
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
```

[129]Identification accuracy will begin to deteriorate, however, when the window length is increased beyond the point at which the modal response amplitude decays below the noise floor.

```
$ JOBNAME:=INIT_20_50_LOOPOP2
$!
$ INPUT1:=_MMST_NAS_SH1_20_50
$ INPUT2:=_MMST_NAS_SH2_20_50
$ INPUT3:=_MMST_NAS_SH3_20_50
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                        MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                        MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                        MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                        MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=81/
S/MRH=/MRH=520/
S/MIC=/MIC=3/
S/MST=/MST=104/
S/MTIM=/MTIM=1920/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=60.,FMIN=20.
 LOOPOP=2,PAR=0,290,10
 IREFTU=1,ITAPES=88,ITAPE(50)=0
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!             [ALWAYS USE EXACTLY 5 LINES]
$!
 INITIAL ANALYSIS OF MINI-MAST DATA
 FILTERED DATA: 20 - 50 HZ
 SLIDING WINDOW ANALYSIS: 0-5 SEC (30 CASES)
 USING DEFAULT S.V. CUTOFF
 INIT_20_50_LOOPOP2:
```

Before you execute this job, you must modify the input and output directory names (Field 1 of the User Input file). These directories are currently [PAPPA.DEMO] which will not exist on your computer system.

Copy the User Input file into your default directory and execute it as follows:

```
COPY ERA$MMST_NAS:INIT_20_50_LOOPOP2.ERA []

ERA INIT_20_50_LOOPOP2
```

This ERA analysis required approximately 32 minutes of CPU time on the author's VAXstation 3100 computer.

The results (identified frequencies) can be plotted with GO Input file G15F_LO2_20_50_DEMO.COM. Here is a listing of this file:

```
$! G15F_LO2_20_50_DEMO.COM
$!
$ RUN ERA$EXES:ERAG15
85INIT_20_50_LOOPOP2     TAPE85 FILE NAME
1       FIRST CASE TO PLOT
30      LAST CASE TO PLOT
.1      DELTA FOR Y-AXIS MINOR TIC MARKS  (0.0 = NONE)
20      FMIN TO PLOT
50      FMAX TO PLOT
1       DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS  (0.0 = NONE)
1       NO. OF PLOTS
4       ACCURACY INDICATOR TO USE AS CUT-OFF?  1=EMAC, 2=MPC-W, 3=MPC-U, 4=CMI
1       MINIMUM ACCURACY INDICATOR VALUE (%) TO INCLUDE?
1       USE DEFAULT Y-AXIS LABEL (BASED ON THE VALUE OF IOPT)?  1=YES
0.4     CHARACTER SIZE IN CM
1       FONT TYPE
0       Y-AXIS GRID LINES?  1=YES
0       ADD ADDITIONAL DOTTED VERTICAL LINES?  1=YES
0       SAVE (FREQ,ACCURACY INDICATOR) RESULTS IN A FILE?  1=YES
1       USE DEFAULT OVERALL WINDOW SIZE?  1=YES
0       MODIFY DEFAULT AXIS NUMBERS?  1=YES
```

Copy the file into your default directory and execute it as follows:[130]

```
COPY ERA$GO:G15F_LO2_20_50_DEMO.COM []

GO G15F_LO2_20_50_DEMO
```

Fig. 3-16 shows the resulting plot.

[130]You also need file G15_OPTIONS.DAT in your working directory. This "hidden options" file was copied from directory ERA$OPTIONS (file G15_OPTIONS_DEMO.DAT) when Fig. 3-12 was plotted.

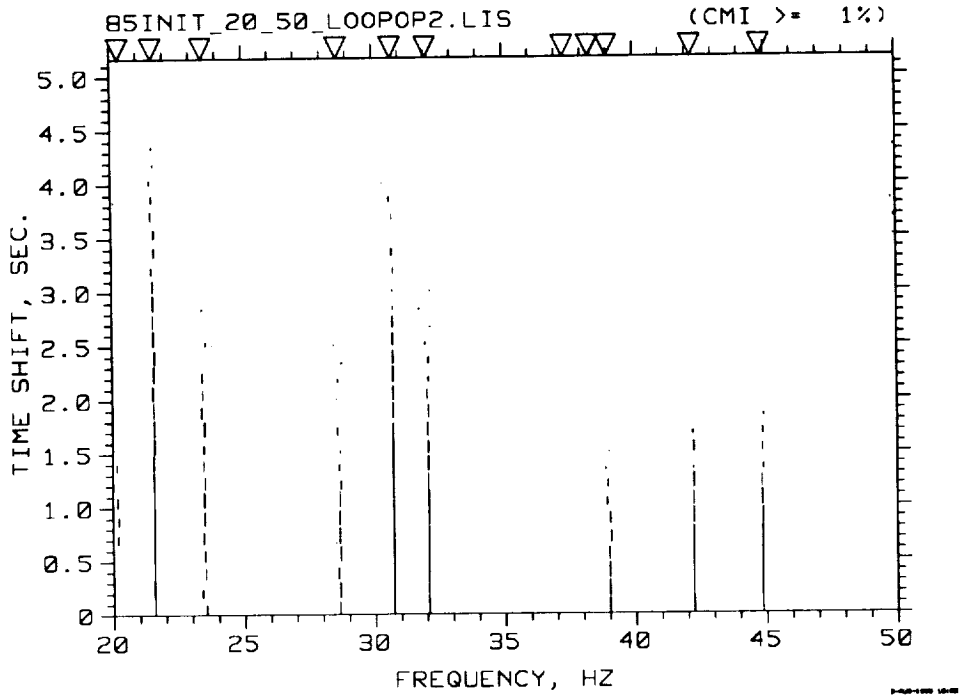


Fig. 3-16. Sliding Window Frequency Results [G15F_LO2_20_50_DEMO]

Next, copy file G15_8_LO2_30TO33_DEMO.COM into your default directory and execute it as follows:

```
COPY ERA$GO:G15_8_LO2_30TO33_DEMO.COM []

GO G15_8_LO2_30TO33_DEMO
```

Here is a listing of this GO Input file:

```
$! G15_8_LO2_30TO33_DEMO.COM
$!
$ RUN ERA$EXES:ERAG15
85INIT_20_50_LOOPOP2      TAPE85
1           FIRST CASE TO PLOT
30          LAST CASE TO PLOT
0.2         DELTA FOR Y-AXIS MINOR TIC MARKS  (0.0 = NONE)
30          FMIN TO PLOT
33          FMAX TO PLOT
0.2         DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS  (0.0 = NONE)
8           NO. OF PLOTS PER PAGE?  MAX. = 8
1           PUT ALL PLOTS ON 1 PAGE(1) OR SEPARATE PAGES(2)
2 PLOT 2: 2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
0.0         MIN. PLOT VALUE
```

```
2.0          MAX. PLOT VALUE
0.2          DELTA PLOT VALUE
7 PLOT 3: 2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
0            MIN. PLOT VALUE
30           MAX. PLOT VALUE
1            DELTA PLOT VALUE
3 PLOT 4: 2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
1            AXIS TYPE? 0=LINEAR, 1=LOG
1E-9         MIN. PLOT VALUE
1E-4         MAX. PLOT VALUE
10           DELTA PLOT VALUE
8 PLOT 5: 2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
0            MIN. PLOT VALUE
101          MAX. PLOT VALUE
10           DELTA PLOT VALUE
4 PLOT 6: 2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
0            MIN. PLOT VALUE
101          MAX. PLOT VALUE
10           DELTA PLOT VALUE
12 PLOT 7:2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
0            MIN. PLOT VALUE
101          MAX. PLOT VALUE
10           DELTA PLOT VALUE
ERA$MMST_NAS:MMST_NASEIGV_900110_TESTDOFS.UNV    NASTRAN MODE SHAPE FILE
121          NASTRAN MODE TO CORRELATE WITH
             TAPE88 FILE?  DEFAULT = 88.. (OTHERWISE SAME AS TAPE85 NAME)
ERA$MMST_NAS:MMST.LOC      TEST-ANALYSIS MAPPING FILE
12 PLOT 8:2=DAMP.,3=AMP.,4=MPCW,5=MPCU,6=EMAC,7=MSR,8=CMI,9=PHS,10=ZETA2,11=PRC,
12=MAC,13=RECIP
0            MIN. PLOT VALUE
101          MAX. PLOT VALUE
10           DELTA PLOT VALUE
122          NASTRAN MODE TO CORRELATE WITH
4            ACC. IND. TO USE AS CUT-OFF?  1=EMAC,2=MPC-W,3=MPC-U,4=CMI,99=NONE
1            MINIMUM ACCURACY INDICATOR VALUE (%) TO INCLUDE?
1            USE DEFAULT Y-AXIS LABEL (BASED ON THE VALUE OF IOPT)?  1=YES
0.25         CHARACTER SIZE IN CM
1            FONT TYPE. 1=STICK
0            X-AXIS GRID LINES?  1=YES
0            ADD ADDITIONAL DOTTED VERTICAL LINES?  1=YES
1            CHAR. SIZE FOR NUMBERS IN PLOTS 2+.   1=STD
0            SAVE FREQ./INDICATOR RESULTS IN A FILE?  1=YES
1            USE DEFAULT OVERALL WINDOW SIZE?  1=YES
0            MODIFY DEFAULT AXIS NUMBERS?  1=YES
```

Fig. 3-17 shows the resulting plot.

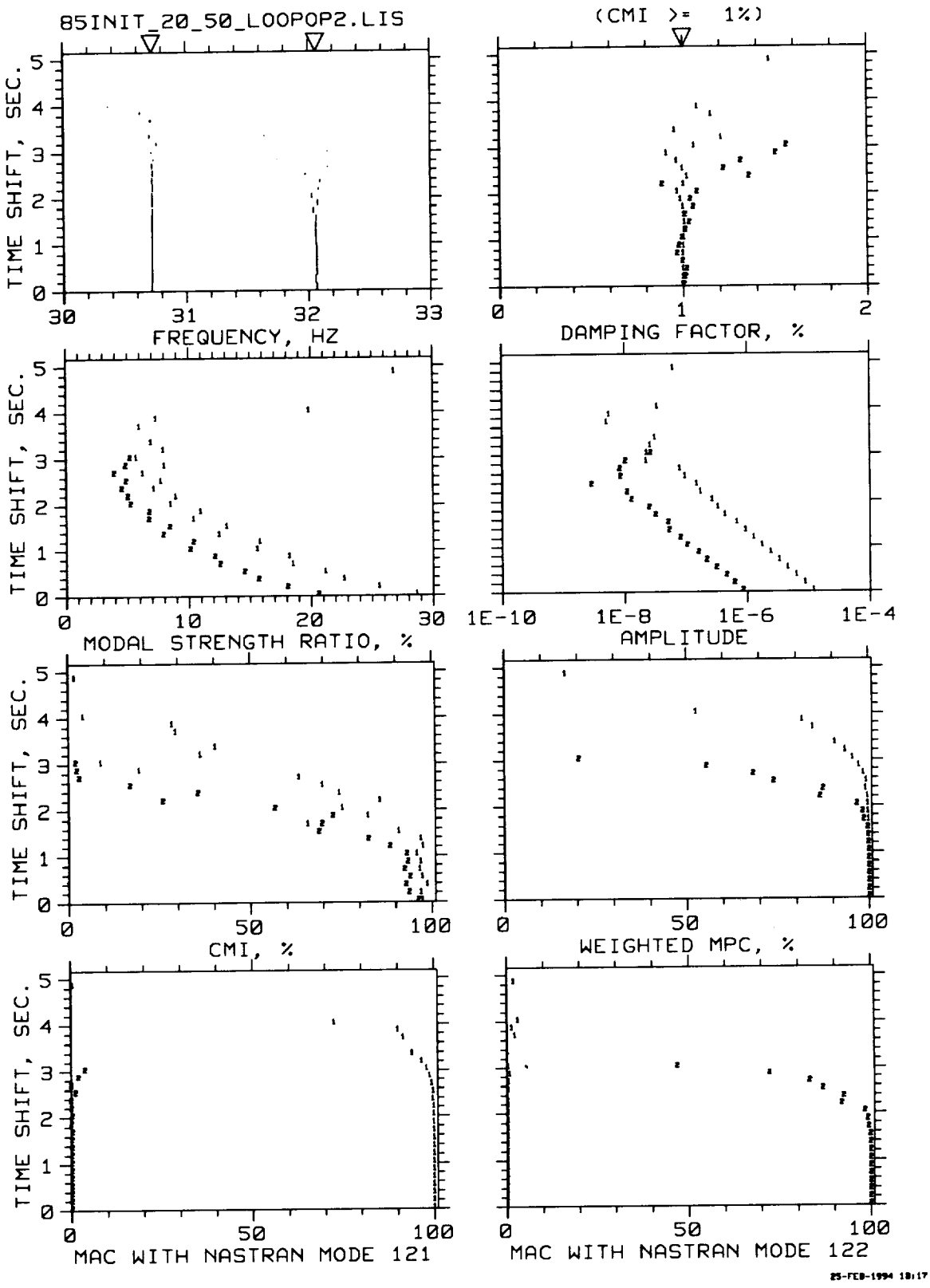


Fig. 3-17. Sliding Window Results From 30 to 33 Hz [G15_8_LO2_30TO33_DEMO.COM]

In Fig. 3-17, damping factor, modal strength ratio, amplitude, CMI, weighted MPC, and MAC with 2 different NASTRAN modes occur in addition to frequency. Program ERAG15 permits any of the following quantities to be selected for any of the additional plots:[131]

```
 2. DAMPING
 3. AMPLITUDE
 4. MPC-W
 5. MPC-U
 6. EMAC
 7. MODAL STRENGTH RATIO (MSR)
 8. CMI (CMI = EMAC * MPC-W)
 9. PHASE
10. ZETA2 (ALTERNATE DAMPING ESTIMATE)
11. PHASE RESONANCE CRITERION
12. MAC WITH A SPECIFIED NASTRAN MODE
13. RECIPROCITY
14. NO. OF RETAINED SINGULAR VALUES
```

These additional data are plotted using small numerals corresponding to each mode appearing in the upper-left, frequency figure. Results for the lowest-frequency mode (along each row of the frequency results) use a "1", results for the second-lowest-frequency mode (along the same row) use a "2", and so forth. In this example, there are 2 modes in the specified frequency interval.

Nonlinearity is indicated by varying frequency and/or damping values as a function of response amplitude (smaller response amplitudes occur at larger time shifts), or nonlinear slope of the logarithmic amplitude plot. Because this demonstration problem uses linear, simulated data, nonlinearity is not observed here. Apparent nonlinearity (data scatter) occurs at time shifts greater than approximately 1.5 seconds because of the decreasing signal-to-noise ratio. Several examples of real structural nonlinearity characterized by this approach appear in other publications, e.g. Refs. 5, 11, and 23.

3.12 Examining Distribution of CMI Values (ERAG3B)

The distribution of Consistent-Mode Indicator (CMI) values indicates the relative accuracy of the identified modes (Ref. 8 and Section 2.6.1). Modes with CMI values greater than approximately 80 percent have with high confidence. Modes with indicator values ranging from approximately 80 to 1 percent have moderate to large uncertainty. Fictitious "computational modes" have CMI values of approximately zero.

[131] Parameter No. 1 is missing from the list because the software assigns it to FREQUENCY, which always appears as the first plot.

Post-processor program ERAG3B plots CMI (or EMAC) values from the Tape85 output file. To illustrate the use of ERAG3B, a sample GO input file named G3B_CMI_DEMO.COM is available in the ERA$GO directory. Copy this file into your default directory and execute it as follows:

```
COPY ERA$GO:G3B_CMI_DEMO.COM []

GO G3B_CMI_DEMO
```

Fig. 3-18 shows the resulting plot.

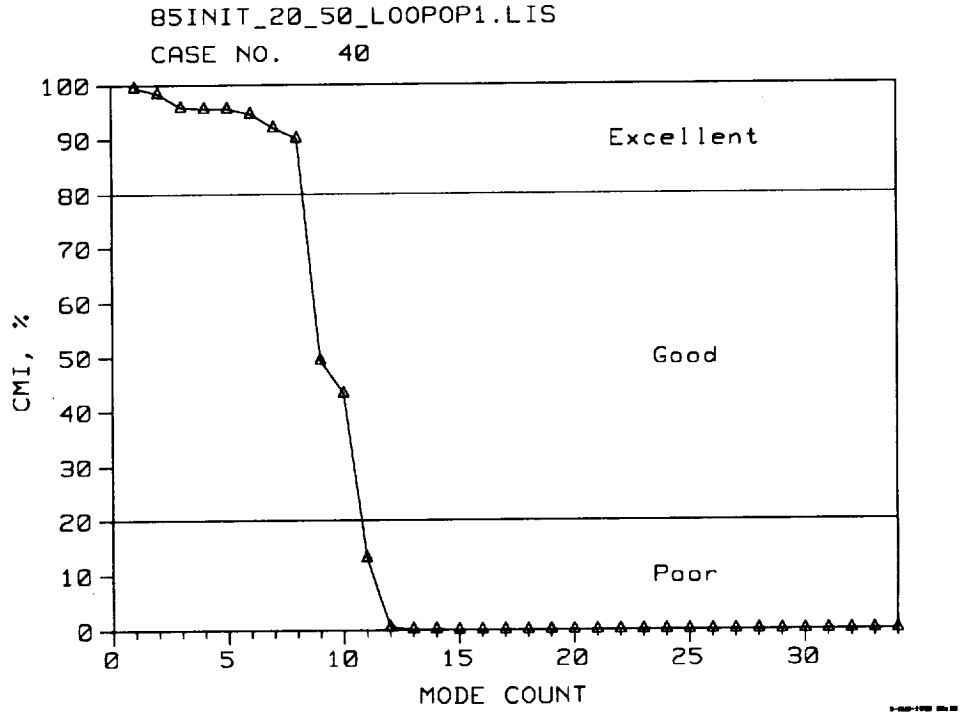


Fig. 3-18. Distribution of CMI Values For Job INIT_20_50_LOOPOP1 Using 40 Assumed Modes [G3B_CMI_DEMO]

Here is a listing of file G3B_CMI_DEMO.COM:

```
$! G3B_CMI_DEMO.COM
$!
$ RUN ERA$EXES:ERAG3B
85INIT_20_50_LOOPOP1   TAPE85 FILE NAME
2       PLOT EMAC(1) OR CMI(2) ?
40      FIRST CASE TO PLOT
40      LAST CASE TO PLOT
1       SORT EMAC OR CMI IN DESCENDING ORDER ? 1=YES
1       DELTA FOR X-AXIS MINOR TIC MARKS
10      DELTA FOR Y-AXIS MINOR TIC MARKS
0.4     CHARACTER SIZE IN CM ?
```

```
1       FONT TYPE.  1=STICK
0.7     SYMBOL SIZE, AS A FRACTION OF CHARACTER SIZE
0       INCLUDE X-AXIS GRID LINES AT EACH TIC ?  1=YES
0       INCLUDE Y-AXIS GRID LINES AT EACH TIC ?  1=YES
1       DRAW HORIZONTAL LINES AT 20% AND 80%?  1=YES
25      X VALUE (E.U.) ABOUT WHICH TO CENTER THE WORDS "EXCELLENT," ETC.
1       USE DEFAULT OVERALL WINDOW SIZE?  1=YES
0       MODIFY DEFAULT AXIS NUMBERS ?  1=YES
```

If you prefer to plot unsorted CMI values, change the response to question 5 ("Sort EMAC or CMI in Descending Order? 1=yes") to "0". This will generate a plot of CMI values versus actual Eigenvalue Number. These Eigenvalue Numbers correspond to those appearing on Tape50. If you prefer to plot the Extended Modal Amplitude Coherence (EMAC) rather than CMI, this can also be done by changing the response of question 2 to "1". You may select other case numbers by modifying the responses to questions 3 and 4.

The following information appears on your computer screen when G3B_CMI_DEMO is run:

```
ERAG3B.  PLOT EMAC OR CMI VALUES FROM TAPE85, IN NORMAL OR DESCENDING ORDER.

TAPE85 FILENAME ?  [DEFAULT FILE TYPE = .LIS])
85INIT_20_50_LOOPOP1.LIS

PLOT EMAC(1) OR CMI(2) ?  (2)
          2

FIRST CASE NO. TO PLOT ?  (1)
         40

LAST CASE NO. TO PLOT ?  (1)
         40

SORT DATA (EMAC OR CMI) IN DESCENDING ORDER ? 1=YES (0)
          1

DELTA FOR X-AXIS MINOR TIC MARKS ?  (2)
          1

DELTA FOR Y-AXIS MINOR TIC MARKS ?  (2)
         10

CHARACTER SIZE (HT.) FOR PLOT LABELS, IN CM ?  (0.3)
 0.4000000

FONT TYPE ?  (1)
 1 = STICK FONT
 2 = LETTER QUALITY - BOLD
 3 = LETTER QUALITY - STD.
          1
```

```
SYMBOL SIZE, AS A FRACTION OF CHARACTER SIZE ?  (0.7)
 0.7000000

INCLUDE X-AXIS GRID LINES (AT EACH TIC) ?  1=YES  (1)
          0

INCLUDE Y-AXIS GRID LINES (AT EACH TIC) ?  1=YES  (1)
          0

DRAW HORIZONTAL LINES AT 20% AND 80% ? 1=YES (1)
          1

X VALUE (E.U.) ABOUT WHICH TO CENTER THE WORDS: EXCELLENT,
GOOD, & POOR ? (30.0)
  25.00000

USE THE DEFAULT OVERALL WINDOW SIZE ? 1=YES  (1)
          1

MODIFY DEFAULT AXIS NUMBERS ?  1=YES  (0)
          0

GRAPHICS DEVICE NUMBER ?  (4)
  1 = TEK. 4010
  2 = TEK. 4014
  3 = TEK. 4025
  4 = TEK. 4107
  5 = TEK. 4115B
  6 = HP 2647/2648
  7 = DEC VT240
  8 = HPGL TALL
  9 = HPGL WIDE
 10 = POSTSCRIPT TALL
 11 = POSTSCRIPT WIDE
```

3.13 Improvement of Results Using High Numbers of Assumed Modes

Improvement of identification accuracy for some modes is normally achieved by using high numbers of assumed modes, i.e., a high number of retained singular values (see, e.g., Ref. 11). The size of the Hankel matrices increases accordingly.[132] This section illustrates the effects of increasing the maximum number of assumed modes from 40 to 100. The size of the Hankel matrices increases from 520 x 81 to 1040 x 201. These results can be directly compared with those presented previously in Section 3.10 using the smaller numbers of assumed modes and Hankel matrix size.

[132]The maximum number of retained singular values $M = \min(n_r, n_c)$, where n_r is the number of rows in the Hankel matrix $H_{rs}(0)$ and n_c is the number of columns, ref. Eqs. 2-17, 2-22.

User Input file INIT_20_50_LO1_TO100.ERA stored in directory ERA$MMST_NAS performs this analysis. Copy this file into your working directory as follows:

```
COPY ERA$MMST_NAS:INIT_20_50_LO1_TO100.ERA []
```

Here is a listing of file INIT_20_50_LO1_TO100.ERA:

```
$! INIT_20_50_LO1_TO100.ERA
$!
$! INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  [PAPPA.DEMO]
$ DEFINE ERA_OUTPUT$ [PAPPA.DEMO]
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=INIT_20_50_LO1_TO100
$!
$ INPUT1:=_MMST_NAS_SH1_20_50
$ INPUT2:=_MMST_NAS_SH2_20_50
$ INPUT3:=_MMST_NAS_SH3_20_50
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=201/
S/MRH=/MRH=1040/
S/MIC=/MIC=3/
S/MST=/MST=104/
S/MTIM=/MTIM=1920/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=60.,FMIN=20.
 LOOPOP=1,PAR=4,200,4
 ITAPES=88,ITAPE(50)=0
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!            [ALWAYS USE EXACTLY 5 LINES]
$!
 LINE 1 FOR COMMENTS
 INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
 FILTERED DATA: 20 - 50 HZ
 NO. ASSUMED MODES = 2,100,2 (RETAINED SV'S = 4,200,4)
```

```
INIT_20_50_LO1_TO100:
```

The number of assumed modes is incremented from 2 to 100 in steps of 2 by the command LOOPOP=1,PAR=4,200,4 in Field 4.[133] **The LOOPOP=1 command increments the number of retained singular values.** The 3 parameters following PAR= specify the first, last, and increment values (FORTRAN syntax).

Before submitting this job, be sure to change the names of the input and output directories located in Field 1. These directories are currently [PAPPA.DEMO] which will not exist on your computer system.

This analysis requires considerable computer time. Approximately 3 hours and 20 minutes of CPU time was required on the author's VAXstation 3100-M76 computer.

Execute this ERA analysis as a batch job as follows:

```
ERA INIT_20_50_LO1_TO100
```

The identified natural frequencies are plotting using GO Input file G15F_20_50_TO100_DEMO.COM. Here is a listing of this file:

```
$! G15F_20_50_TO100_DEMO.COM
$!
$ RUN ERA$EXES:ERAG15
85INIT_20_50_LO1_TO100      TAPE85 FILE NAME
1       FIRST CASE TO PLOT
50      LAST CASE TO PLOT
2       DELTA FOR Y-AXIS MINOR TIC MARKS  (0.0 = NONE)
20      FMIN TO PLOT
50      FMAX TO PLOT
1       DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS  (0.0 = NONE)
1       NO. OF PLOTS
4       ACCURACY INDICATOR TO USE AS CUT-OFF?  1=EMAC, 2=MPC-W, 3=MPC-U, 4=CMI
1       MINIMUM ACCURACY INDICATOR VALUE (%) TO INCLUDE?
1       USE DEFAULT Y-AXIS LABEL (BASED ON THE VALUE OF IOPT)?  1=YES
0.4     CHARACTER SIZE IN CM
1       FONT TYPE
0       Y-AXIS GRID LINES?  1=YES
0       ADD ADDITIONAL DOTTED VERTICAL LINES?  1=YES
0       SAVE (FREQ,ACCURACY INDICATOR) RESULTS IN A FILE?  1=YES
1       USE DEFAULT OVERALL WINDOW SIZE?  1=YES
0       MODIFY DEFAULT AXIS NUMBERS?  1=YES
```

[133]Recall that the number of assumed modes equals one-half the number of retained singular values. Each mode corresponds to a complex-conjugate pair of eigenvalues. The LOOPOP parameter is described completely in Chapter 6.

Copy this file into your working directory and execute it as follows:[134]

```
COPY ERA$GO:G15F_20_50_TO100_DEMO.COM []

GO G15F_20_50_TO100_DEMO
```

Fig. 3-19 shows the resulting plot.

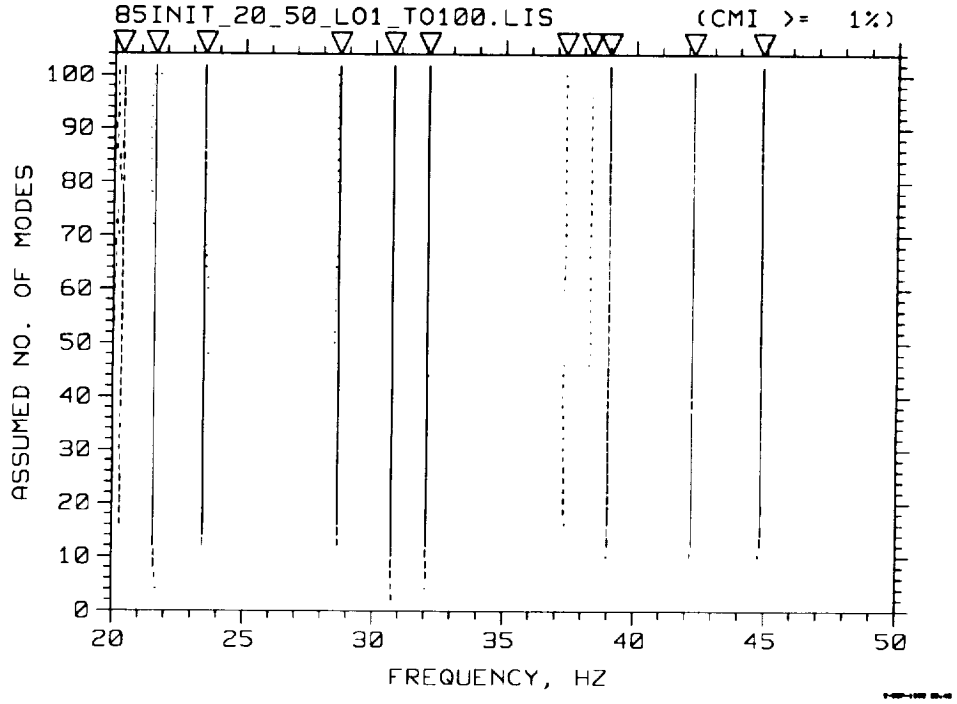


Fig. 3-19. Identified Natural Frequencies Using High Nos. of Assumed Modes [G15F_20_50_TO100_DEMO]

Fig. 3-19 can be directly compared with Fig. 3-12 which shows corresponding results using up to 40 assumed modes. Based on the lengths of the vertical dashes in these figures (proportional to CMI), the following modes are identified with higher accuracy using high numbers of assumed modes: 20.3 Hz, 23.5 Hz, and 28.6 Hz.[135] However, the following modes are identified with somewhat lower accuracy: 39.0 Hz and 42.2 Hz. Also, more computational modes occur in Fig. 3-19 than in Fig. 3-12. Computational modes have very low CMI values, approximately 1%, and appear as dots in the figures.

[134]You also need file G15_OPTIONS.DAT in your working directory. This "hidden options" file was copied from directory ERA$OPTIONS (file G15_OPTIONS_DEMO.DAT) when Fig. 3-12 was plotted.

[135]A list of the NASTRAN natural frequencies for the demonstration problem is available in Section 15.13.

The 3 modes shown previously (individually) in Figs. 3-13, 3-14, and 3-15 are now presented again in **Figs. 3-20, 3-21, and 3-22** for the INIT_20_50_LO1_TO100 analysis. These figures show results for a strongly excited mode (30.7 Hz), a moderately excited mode (23.5 Hz), and a weakly excited mode (37.3 Hz), respectively. Figs. 3-20 through 3-22 are generated with GO Input files G15_8_30P7_TO100_DEMO.COM, G15_8_23P5_TO100_DEMO.COM, and G15_8_37P3_TO100_DEMO.COM.

Using high numbers of assumed modes, there is considerable improvement in accuracy for the moderately excited mode at 23.5 Hz. Some improvement of accuracy is also obtained for the other 2 modes but the degree of improvement is less. One noteworthy aspect of the results with high numbers of assumed modes occurs in Fig. 3-22 for the weakly excited mode at 37.3. The results for EMAC (and CMI) vs the number of assumed modes in this case are opposite of that which normally occurs. That is, EMAC values generally increase vs assumed number of modes but here they decrease. The explanation is that the additional assumed modes add not only extra degrees-of-freedom to the model (which generally improves accuracy for structural modes), but they also add additional noise to the model corresponding to small singular values which can reduce accuracy for weakly excited modes.

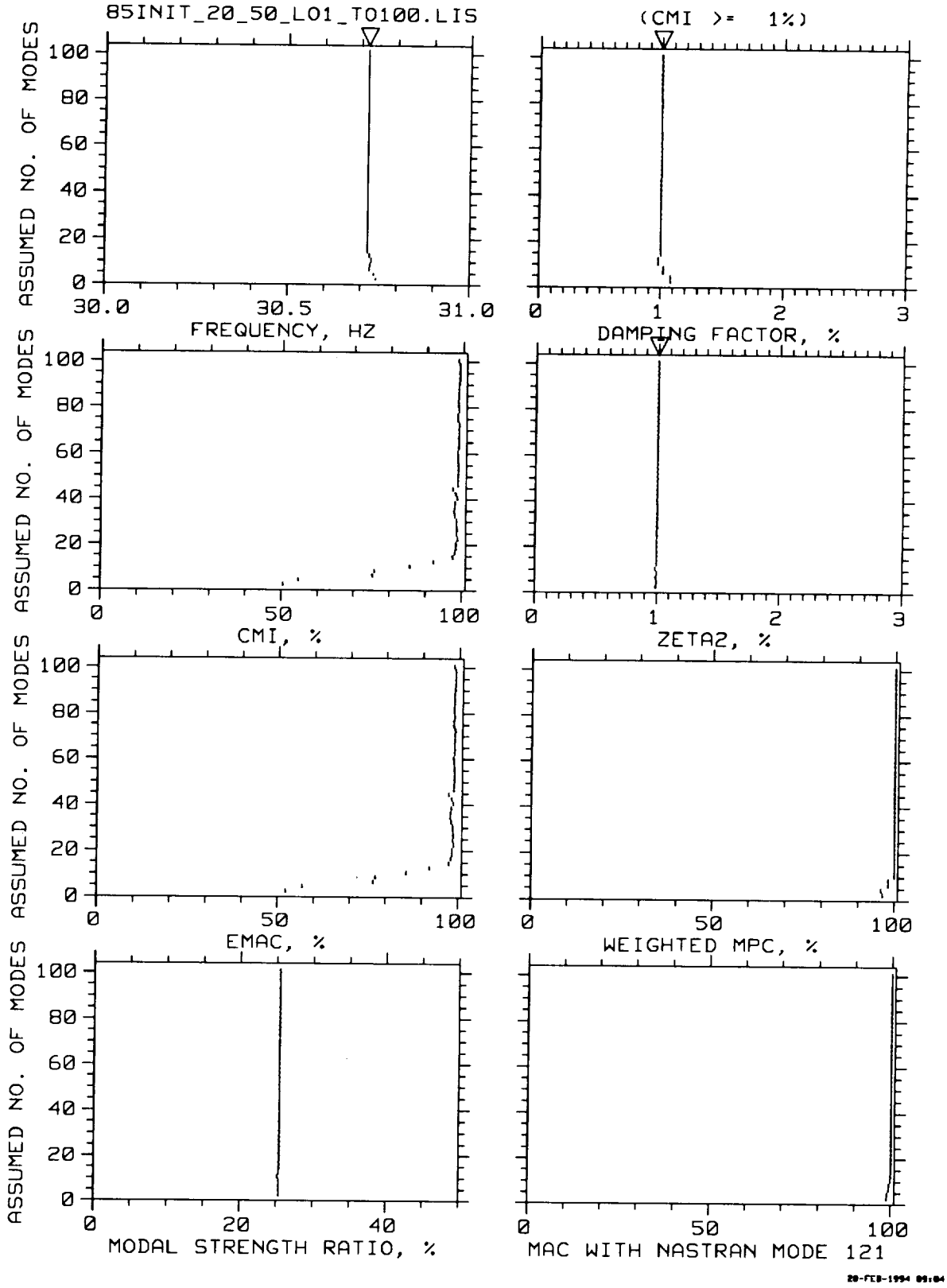


Fig. 3-20. Results For Strongly Excited Mode at 30.7 Hz Using High Nos. of Assumed Modes [G15_8_30P7_TO100_DEMO.COM]

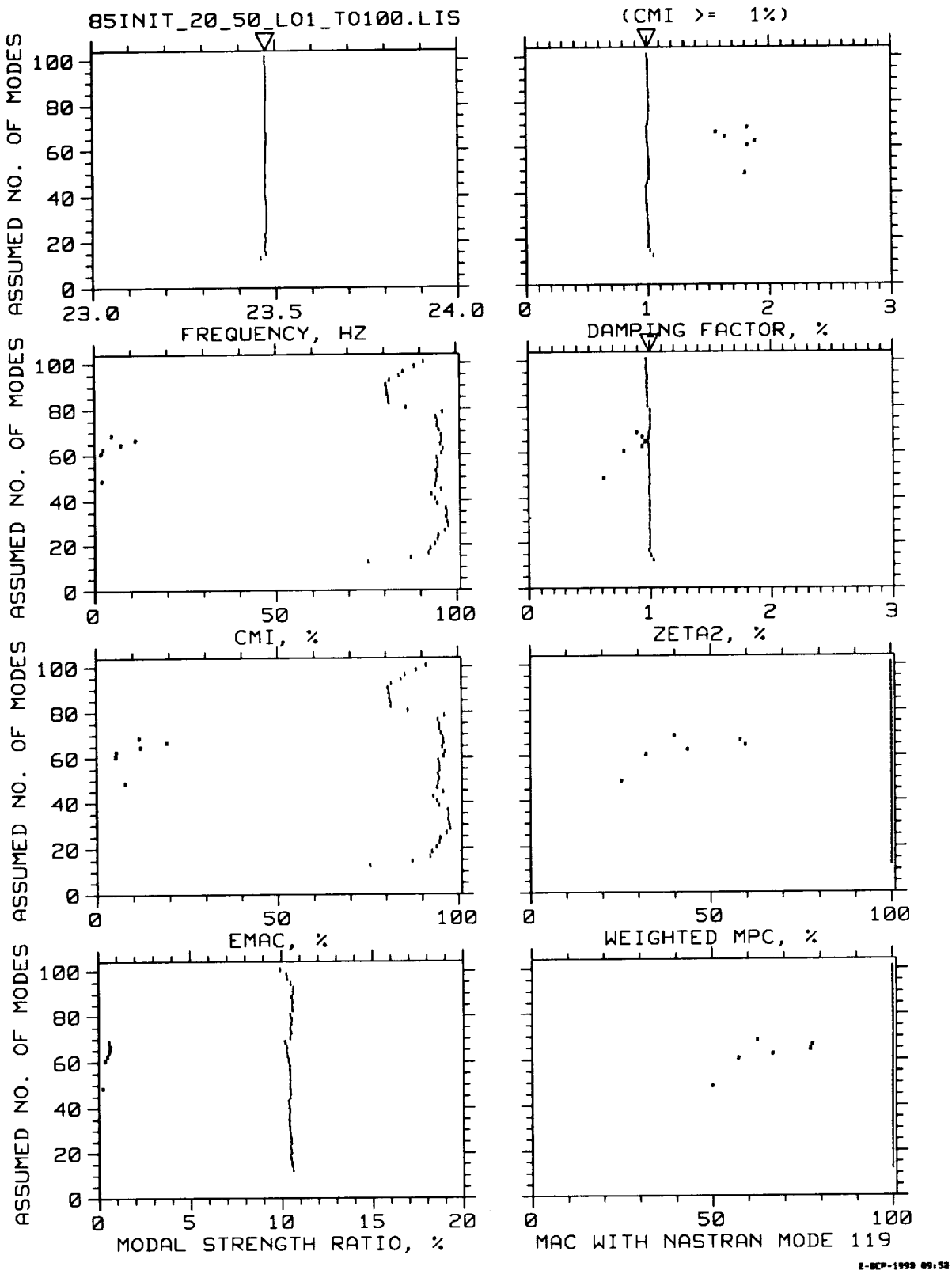


Fig. 3-21. Results For Moderately Excited Mode at 23.5 Hz Using High Nos. of Assumed Modes [G15_8_23P5_TO100_DEMO.COM]

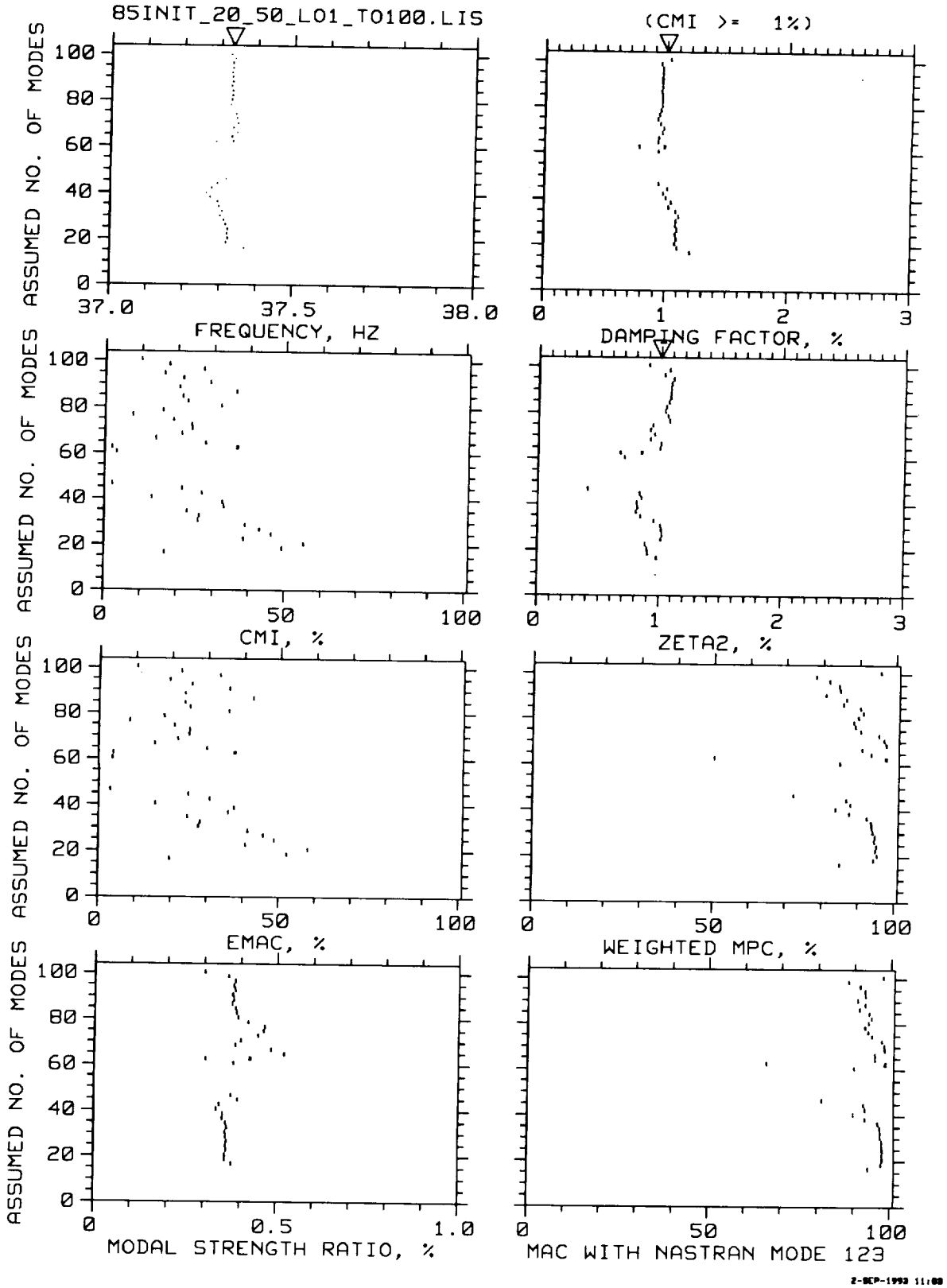


Fig. 3-22. Results For Weakly Excited Mode at 37.3 Hz Using High Nos. of Assumed Modes [G15_8_37P3_TO100_DEMO.COM]

3.14 Improvement of Results Using KEYDTA

In initial ERA analyses, all available data are usually analyzed simultaneously with uniform emphasis (weighting). A global, least-squares estimate of the modal parameters over the entire frequency range of the analysis is obtained. For individual modes, however, these initial results can often be improved in subsequent analyses by emphasizing particular measurements. One method for selecting measurements for emphasis is to use constituent EMAC results obtained in an initial analysis. Constituent EMAC results (i.e., EMAC values for each initial condition and response measurement separately) are written onto output file Tape55. Tape55 is activated by including an ITAPES=55 command in Field 4 of the ERA User Input file. The response measurements selected for emphasis are then specified in a subsequent ERA analysis using (array) parameter KEYDTA.

KEYDTA specifies those response measurements used to fill the rows of the generalized Hankel matrices below row number NST.[136] By default (i.e., if KEYDTA is not included in Field 4 of the User Input file), all NST measurements are used to fill the matrices. The total number of response measurements used to fill the matrices below row number NST is printed in the list of analysis parameters at the beginning of each Tape50 file. It is named NSTBOT, an acronym for the "Number of response STations included in the BOTtom of the Hankel matrices." Also printed on Tape50 is array variable NSFLAG that shows (using 1=yes and 0=no) those measurement numbers specified with KEYDTA. The first NST rows of the generalized Hankel matrices are always filled with data from the NST response measurements, providing complete mode shape results in every analysis.

KEYDTA can also be used to reduce the size of the generalized Hankel matrices when a large number of response measurements are analyzed simultaneously (e.g., when NST is greater than 200). In this situation, because of the large redundancy of information contained in the measurements (for "global" modes having displacement at many measurement locations), only a portion of the measurements need to be included in the Hankel matrices below row NST for accurate modal identification. This software feature allows significant reductions in Hankel matrix sizes when large numbers of response measurements are analyzed simultaneously. Computer time requirements for ERA increase approximately linearly with the larger dimension of the Hankel matrices, which is normally the number of rows. **With this approach, Hankel matrix sizes greater than approximately 1500 rows by 250 columns are rarely used in practice even for large modal survey tests involving 300+ response measurements.** Initial analyses can be performed in minutes of computer time (on a VAXstation 3100), and looping analyses in an hour or so.

[136]The structure of the generalized Hankel matrices is described in Appendix K.

As an example of this capability, KEYDTA is used to improve the identification results for the mode at 37.3 Hz shown previously in Fig. 3-15. An initial analysis is made using 31 assumed modes (IORDER=62), selected from Fig. 3-15 as the case having the highest CMI value, where CMI = EMAC x MPC-W (Ref. 8).[137] This initial analysis is performed with ERA User Input file INIT_20_50_ANM31.ERA listed below. This file is stored in directory ERA$MMST_NAS. The ERA job name is INIT_20_50_ANM31. Remember to modify the input and output directory names (Field 1 of the User Input file) before you perform the analysis. These directories are defined as [PAPPA.DEMO] which will not exist on your computer system.

This ERA analysis using 31 assumed modes required approximately 4 minutes of CPU time on the author's VAXstation 3100.

```
$! INIT_20_50_ANM31.ERA
$!
$! INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  [PAPPA.DEMO]
$ DEFINE ERA_OUTPUT$ [PAPPA.DEMO]
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=INIT_20_50_ANM31
$!
$ INPUT1:=_MMST_NAS_SH1_20_50
$ INPUT2:=_MMST_NAS_SH2_20_50
$ INPUT3:=_MMST_NAS_SH3_20_50
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=81/
S/MRH=/MRH=520/
S/MIC=/MIC=3/
S/MST=/MST=104/
S/MTIM=/MTIM=1920/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
```

[137]This information is printed out when Fig. 3-15 is generated (using file G15_8_37P3_DEMO.COM).

```
 SF=60.,FMIN=20.
 IORDTU=62
 ITAPES=55
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!              [ALWAYS USE EXACTLY 5 LINES]
$!
 LINE 1 FOR COMMENTS
 INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
 FILTERED DATA: 20 - 50 HZ
 NO. ASSUMED MODES = 31 (MAX. CMI FOR 37.3 HZ MODE)
 INIT_20_50_ANM31:
```

Examine output file Tape55 (named 55INIT_20_50_ANM31.LIS). The following information occurs for the target mode at approximately 37.3 Hz:

File 55INIT_20_50_ANM31.LIS (partial)

```
   E.V.  FREQUENCY,  DAMPING                          AVG.    EMACS >= 80%                                                  RECIP-
    NO.    HERTZ    FACTOR, % (ZETA2,%)     CMI,%     EMAC,%   INPUT  OUTPUT    MPC-W   MPC-U   PRC    ARATIO   PROCITY  MSR,%
                                                                (   3) ( 104)
-------------------------------------------------------------------------------------------------------------------------------
 16  16    37.304      1.061   ( 1.016)  :  60.21     62.02  :     1     24  :  97.09   57.59   950  :  0.149  :  52.3    0.4

UNWEIGHTED INPUT EMACS:
  87.    67.     0.

INPUT MODE SHAPE:
 1000   -764    306

WEIGHTED INPUT EMACS:
  87.+   39.     0.

UNWEIGHTED OUTPUT EMACS:
  69.    68.    85.    73.    74.    82.    74.    68.    50.    71.
  73.    90.    63.    69.    68.    80.    87.    65.    42.     0.
  21.     9.     0.     0.    78.     0.    58.    58.     3.     3.
  67.    46.     0.    70.    29.     0.    77.     0.    68.    73.
   0.    87.    72.    46.     7.    60.     0.    30.     0.     0.
   0.    95.    90.    94.    93.    92.    91.    85.    78.    90.
  89.    84.    95.    79.    91.    91.    80.    90.    85.    56.
  64.    99.     0.     0.     0.    54.     0.    69.    50.     0.
  65.    76.    69.    77.    52.    34.    72.    85.    46.    66.
  85.    68.    71.    67.    75.    10.    80.     0.    94.     0.
  13.    30.    76.     0.

OUTPUT MODE SHAPE:
 112   -119   -138    135   -172   -168    135   -167   -163    102
-195   -198     89   -147   -143     75   -126   -119     47    -64
 -42     50    -46    -28    -42     63     86   -133     40     31
-168     74     27   -287     56     29   -261    -18     47   -316
 -31     59   -254    -67     10   -159    -90    -10    -49     27
   9    520    407    658    691    508    881    803    608    945
 786    629   1000    673    525    816    503    406    582    267
 259    336     43     35     75   -121    -81   -161   -229    -23
-337   -314   -120   -488   -323   -202   -586   -383   -253   -604
-399   -230   -517   -275   -224   -318   -217    -57   -265    -88
  23    -91    -51    -18

WEIGHTED OUTPUT EMACS:
   1.     1.     2.     1.     2.     2.     1.     2.     1.     1.
   3.     4.     0.     1.     1.     0.     1.     1.     0.     0.
   0.     0.     0.     0.     0.     0.     0.     1.     0.     0.
   2.     0.     0.     6.     0.     0.     5.     0.     0.     7.
   0.     0.     5.     0.     0.     2.     0.     0.     0.     0.
   0.    26.    15.    41.    44.    24.    71.    55.    29.    81.+
  55.    33.    95.*   36.    25.    60.    20.    15.    29.     4.
   4.    11.     0.     0.     0.     1.     0.     2.     3.     0.
   7.     8.     1.    18.     5.     1.    25.    12.     3.    24.
  14.     4.    19.     5.     4.     1.     4.     0.     7.     0.
   0.     0.     0.     0.

WEIGHTED OUTPUT EMACS IN DESCENDING ORDER:
  95.    81.    71.    60.    55.    55.    44.    41.    36.    33.
  29.    29.    26.    25.    25.    24.    24.    20.    19.    18.
  15.    15.    14.    12.    11.     8.     7.     7.     7.     6.
```

```
   5.    5.    5.    5.    4.    4.    4.    4.    4.    4.
   3.    3.    3.    2.    2.    2.    2.    2.    2.    2.
   1.    1.    1.    1.    1.    1.    1.    1.    1.    1.
   1.    1.    1.    1.    1.    0.    0.    0.    0.    0.
   0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
   0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
   0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
   0.    0.    0.    0.

CORRESPONDING MEASUREMENT NOS.:
  63    60    57    66    58    61    55    54    64    62
  69    59    52    65    87    90    56    67    93    84
  53    68    91    88    72    82    81    40    99    34
  85    37    94    43    71    70    95    97    92    12
  89    11    79     6     5     8    31    78     3    46
  14    15    86    17     7     9     4    96    28    83
   2    18     1    76    10    13    16    27    42    32
 102    44   103    39    25    19    35    21    22   101
  29    48    30    45   104   100    98    80    77    75
  74    73    51    50    49    47    41    38    36    33
  26    24    23    20
```

From these results, decide which measurement numbers to specify as KEYDTA. Normally, the decision is based on the distribution of weighted output EMAC values. For some modes, a large drop in EMAC values will occur between those measurements having high EMAC values and those having low EMAC values. For this mode at 37.3 Hz, however, no large, distinct drop in EMAC values occurs (based on the results listed under "Weighted Output EMACs in Descending Order"). For this example problem, the decision was made to select all measurement numbers having a weighted output EMAC greater than 5 percent. Thirty of the 104 measurements satisfy this criterion.

Specifying these 30 measurements as KEYDTA, the following User Input file is used to perform an ERA analysis emphasizing this 37.3 Hz mode. The job name is INIT_20_50_KD37P3_LO1.

This ERA analysis required approximately 14 minutes of CPU time on the author's VAXstation 3100.

```
$! INIT_20_50_KD37P3_LO1.ERA
$!
$! INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  [PAPPA.DEMO]
$ DEFINE ERA_OUTPUT$ [PAPPA.DEMO]
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!        [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=INIT_20_50_KD37P3_LO1
$!
$ INPUT1:=_MMST_NAS_SH1_20_50
$ INPUT2:=_MMST_NAS_SH2_20_50
$ INPUT3:=_MMST_NAS_SH3_20_50
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
```

```
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
$!
S/MCH=/MCH=81/
S/MRH=/MRH=494/
S/MIC=/MIC=3/
S/MST=/MST=104/
S/MTIM=/MTIM=1920/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=60.,FMIN=20.
 LOOPOP=1,PAR=2,80,2
 ITAPES=88,ITAPE(50)=0
 KEYDTA=
    63      60      57      66      58      61      55      54      64      62
    69      59      52      65      87      90      56      67      93      84
    53      68      91      88      72      82      81      40      99      34
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!              [ALWAYS USE EXACTLY 5 LINES]
$!
 LINE 1 FOR COMMENTS
 INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
 FILTERED DATA: 20 - 50 HZ
 NO. ASSUMED MODES = 1,40,1. KEYDTA FOR 37.3 HZ MODE
 INIT_20_50_KD37P3_LO1:
```

The results of job INIT_20_50_KD37P3_LO1 are plotted in **Fig. 3-23** using GO Input file G15_8_KD37P3_DEMO.COM. Comparing these results with those shown in Fig. 3-15, **considerable improvements in the stability of the frequency and damping results and in the magnitude of EMAC (and CMI) are found**. Only a slight corresponding improvement in Weighted MPC is obtained for this particular example. Several examples of significant improvements obtained with experimental data using this KEYDTA approach appear in other publications, e.g. Refs. 8, 11, and 24.

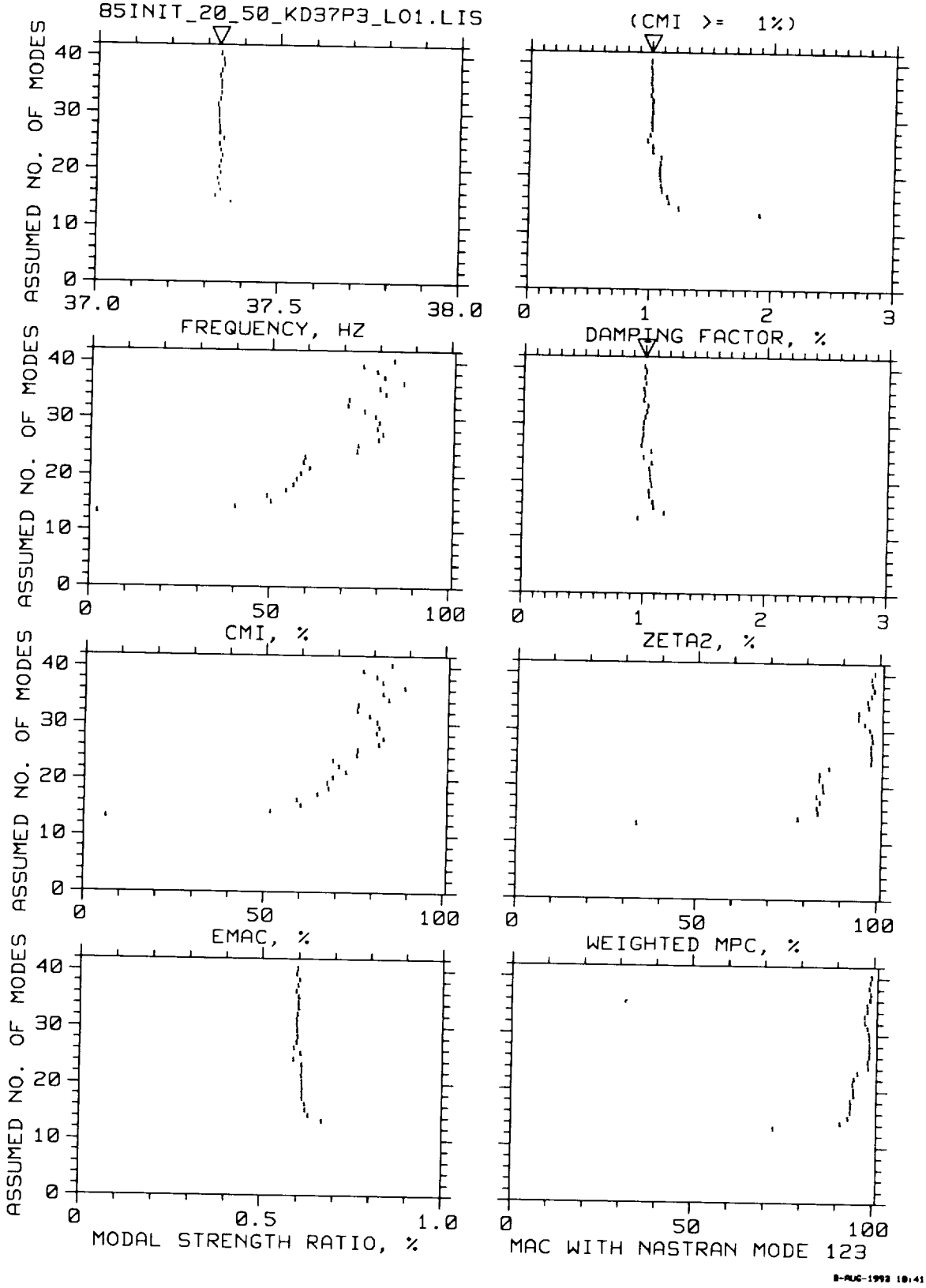


Fig. 3-23. Improvement of Results For Weakly Excited Mode at 37.3 Hz Using KEYDTA (Compare With Fig. 3-15) [G15_8_KD37P3_DEMO.COM]

3.15 Modal Mass Calculation (ERAP11)

This section describes a procedure for calculating modal mass m_r, Eq. 3-13. Equivalently, the ERA-identified mode shapes are scaled to unity modal mass (i.e., $m_r = 1$ with the mode shapes adjusted accordingly), Eq. 3-14.

$$H_{kl}(\omega) = \sum_{r=1}^{N} \frac{\psi_{kr}\psi_{lr} / m_r}{(\omega_{nr}^2 - \omega^2) + j2\zeta_r\omega_{nr}\omega} \tag{3-13}$$

$$= \sum_{r=1}^{N} \frac{\phi_{kr}\phi_{lr}}{(\omega_{nr}^2 - \omega^2) + j2\zeta_r\omega_{nr}\omega} \tag{3-14}$$

$$= \sum_{r=1}^{N} \left(\frac{R_{klr}}{j\omega - p_r} + \frac{R_{klr}^*}{j\omega - p_r^*} \right) \tag{3-15}$$

where: $H_{kl}(\omega)$ = FRF between response measurement k (displacement) and shaker location l (force)

N = No. of modes

ψ_{kr} = Shape of mode r at response measurement k

ψ_{lr} = Shape of mode r at shaker location l

m_r = Mass of mode r

ω_{nr} = Undamped natural frequency[138] of mode r

ω = Frequency in rad/sec = $2\pi f$

f = Frequency in Hz

ζ_r = Viscous damping factor (fraction of critical damping) of mode r

j = $\sqrt{-1}$

ϕ_{kr} = ψ_{kr} scaled to unity modal mass = $\dfrac{\psi_{kr}}{\sqrt{m_r}}$

ϕ_{lr} = ψ_{lr} scaled to unity modal mass = $\dfrac{\psi_{lr}}{\sqrt{m_r}}$

R_{klr} = Residue of response measurement k and shaker location l for mode r

p_r = Pole $r = \sigma_r + j\omega_{dr}$

σ_r = Damping rate of mode $r = -\zeta_r\omega_{nr}$

ω_{dr} = Damped natural frequency of mode $r = \omega_{nr}\sqrt{1-\zeta_r^2}$

$*$ = Complex conjugate

[138]ERA identifies damped natural frequencies, $\omega_{dr} = \omega_{nr}\sqrt{1-\zeta_r^2}$.

ERA identifies initial modal amplitudes (A_{klr}) and phase angles (θ_{klr}), Eq. 3-16, from impulse response functions:[139]

$$h_{kl}(t) = \sum_{r=1}^{N} A_{klr}\, e^{\sigma_r t} \cos(\omega_{dr} + \theta_{klr}) \tag{3-16}$$

where: $h_{kl}(t)$ = IRF between response measurement k and shaker location l

$A_{klr} = 2 \cdot |R_{klr}|$

$\theta_{klr} = \arg(R_{klr})$

By Eqs. 3-13 through 3-16,

$$|R_{klr}| = \left| -j \frac{\psi_{kr}\psi_{lr}}{2\omega_d m_r} \right| = \left| -j \frac{\phi_{kr}\phi_{lr}}{2\omega_d} \right| = \frac{A_{klr}}{2} \tag{3-17}$$

Eq. 3-17 contains 2 unknowns, ϕ_{kr} and ϕ_{lr}. Therefore, **it can be solved only at driving-point locations** ($k = l$), as follows:[140]

$$\overline{\phi}_{kr} = \sqrt{j\omega_d A_{kkr}} \tag{3-18}$$

Eq. 3-18 holds for displacement/force IRFs. If velocity/force or acceleration/force IRFs are analyzed, $\overline{\phi}_{kr}$ must be divided by $\sqrt{\omega_{nr}}$ or ω_{nr}, respectively.

Once the driving-point mode shape component $\overline{\phi}_{kr}$ is obtained, calculate all other components ϕ_{xr} as follows:

$$\phi_{xr} = \overline{\phi}_{kr} \left(\frac{A_{xr}}{A_{kr}} \right) \tag{3-19}$$

Post-processor program ERAP11 prints ERA-identified residues (Eq. 3-17) or mode shapes scaled to unity modal mass (Eqs. 3-18 and 3-19). **The analysis must have included at least one driving-point measurement.** Mode shapes scaled to unity

---

[139] A_{klr} and θ_{klr} in physical units are printed on Tape51 and/or on Tape50 by specifying MSTO50=1. MSTO50 is an acronym for "Mode Shapes TO Tape50."

[140] Eq. 3-17 could be solved for $k \neq l$ if the ratio $\frac{\phi_{kr}}{\phi_{lr}}$ were known. However, this ratio is unknown because the relative scaling of modal participation factors (ϕ_{lr}) and mode shapes (ϕ_{kr}) identified by ERA is indeterminant.

modal mass can be directly compared with corresponding NASTRAN results.[141] For this demonstration problem, the NASTRAN mode shapes are stored in Universal file ERA$MMST_NAS:MMST_NASEIGV_900110_TESTDOFS.UNV. **Program ERAP11 uses the B and C matrices stored on Tape79 (MATRIXx format) to calculate the residues or scaled mod shapes.**[142]

As a demonstration, copy file P11_DEMO.COM into your working directory and execute it in the usual way using GO:

```
COPY ERA$GO:P11_DEMO.COM []

GO P11_DEMO
```

Here is a listing of file P11_DEMO.COM:

```
$! P11_DEMO.COM
$!
$ RUN ERA$EXES:ERAP11
79INIT_20_50      TAPE79 FILENAME
2           WHICH SCALING?  1=RESIDUES, 2=UNITY-MODAL-MASS COEFFICIENTS
1           TYPE OF IRF ANALYZED?  1=D/F, 2=V/F, 3=A/F
1           PRINT REAL [1] OR COMPLEX [2] MODE SHAPES ?
10          FIRST EIGENVALUE NO. TO PRINT
10          LAST  EIGENVALUE NO. TO PRINT
1           FIRST MEASUREMENT NO. TO PRINT
25          LAST  MEASUREMENT NO. TO PRINT
1           FIRST INITIAL CONDITION NO. TO PRINT
3           LAST  INITIAL CONDITION NO. TO PRINT
```

This demonstration calculates mass-scaled mode shape components for measurement numbers 1 through 25 for ERA Eigenvalue No. 10 (42.227 Hz). The following information appears on your computer screen when P11_DEMO.COM is run:

```
ERAP11.  PRINT OUT SCALED MODE SHAPES, USING B AND C MATRICES FROM TAPE79.

TAPE79 FILENAME ?  (DEFAULT FILE TYPE = .DAT))
79INIT_20_50.DAT

WHICH SCALING TO USE ?  ( 2 )
 1. RESIDUES (ASSUMING DATA ARE IRF'S)
 2. UNITY-MODAL-MASS COEFFICIENTS (ASSUMING IRF'S AND NORMAL MODES)
        2

WHICH TYPE OF FRF (IRF) WAS ANALYZED ?  ( 3 )
  1.  D/F
  2.  V/F
  3.  A/F
        1
```

[141]Mode shape scaled to unity modal mass is the default NASTRAN scaling convention. Other scaling methods are available.

[142]Output file Tape79 is activated by including an ITAPES=79 statement in Field 4 of the ERA User Input file. By default, Tape79 is deactivated.

```
PRINT REAL(1) OR COMPLEX(2) MODE SHAPES ?  ( 1 )
        1

* * * NOTE * * * NOTE * * * NOTE * * * NOTE * * * NOTE * * * NOTE * * * NOTE * * *
*                                                                               *
*  REAL MODE SHAPES WILL BE APPROXIMATED FROM THE ERA-IDENTIFIED COMPLEX MODES   *
*  BY ASSIGNING POSITIVE AMPLITUDES IF ABS(PHASE) <= 90 DEGREES AND             *
*  NEGATIVE AMPLITUDES OTHERWISE.                                               *
*                                                                               *
* * * NOTE * * * NOTE * * * NOTE * * * NOTE * * * NOTE * * * NOTE * * * NOTE * * *

NO. OF   REAL  EIGENVALUES ........   7
NO. OF COMPLEX EIGENVALUES ........  12
NO. OF MEASUREMENTS (OUTPUTS) ..... 104
NO. OF INIT. CONDITIONS (INPUTS) ..   3


FIRST EIGENVALUE NO. TO PRINT ?  (  -7)

* * * REAL EIGENVALUES ARE REFERRED TO USING NEGATIVE EIGENVALUE NOS. * * *
        10

LAST EIGENVALUE NO. TO PRINT ?  ( 12)
        10

FIRST MEASUREMENT NO. [OUTPUT NO.] TO PRINT ?  (  1)
         1

LAST MEASUREMENT NO. [OUTPUT NO.] TO PRINT ?  (104)
        25

FIRST INITIAL CONDITION NO. [INPUT NO.] TO PRINT ?  (  1)
         1

LAST INITIAL CONDITION NO. [INPUT NO.] TO PRINT ?  (  3)
         3


* * * REAL EIGENVALUES ARE REFERRED TO USING NEGATIVE EIGENVALUE NOS. * * *


DRIVING PT. MEASUREMENT NOS. =  103  74 104
```

* UNITY-MODAL-MASS COEFFICIENTS *

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	AMPLITUDE & PHASE IN DEGREES — IC # 1	201Z+	IC # 2	23Y+	IC # 3	203Z+
10	42.227	1.003	1X+	1	**9.9450E-02**	0.0	9.9292E-02	0.0	9.9717E-02	0.0
			2X+	2	**9.4346E-02**	0.0	9.4196E-02	0.0	9.4600E-02	0.0
			3X+	3	**9.5120E-02**	0.0	9.4969E-02	0.0	9.5376E-02	0.0
			4X+	4	**1.2009E-01**	0.0	1.1990E-01	0.0	1.2042E-01	0.0
			5X+	5	**1.1765E-01**	0.0	1.1747E-01	0.0	1.1797E-01	0.0
			6X+	6	**1.1607E-01**	0.0	1.1589E-01	0.0	1.1639E-01	0.0
			7X+	7	**1.3013E-01**	0.0	1.2992E-01	0.0	1.3048E-01	0.0
			8X+	8	**1.2290E-01**	0.0	1.2278E-01	0.0	1.2331E-01	0.0
			9X+	9	**1.2411E-01**	0.0	1.2391E-01	0.0	1.2444E-01	0.0
			10X+	10	**1.1475E-01**	0.0	1.1456E-01	0.0	1.1506E-01	0.0
			11X+	11	**1.1175E-01**	0.0	1.1157E-01	0.0	1.1205E-01	0.0
			12X+	12	**1.1017E-01**	0.0	1.0999E-01	0.0	1.1046E-01	0.0
			13X+	13	**8.7852E-02**	0.0	8.7712E-02	0.0	8.8088E-02	0.0
			14X+	14	**8.2033E-02**	0.0	8.1903E-02	0.0	8.2254E-02	0.0
			15X+	15	**8.2719E-02**	0.0	8.2588E-02	0.0	8.2942E-02	0.0
			16X+	16	**4.5462E-02**	0.0	4.5390E-02	0.0	4.5584E-02	0.0
			17X+	17	**4.3880E-02**	0.0	4.3810E-02	0.0	4.3998E-02	0.0
			18X+	18	**4.3175E-02**	0.0	4.3107E-02	0.0	4.3292E-02	0.0
			19X+	19	**3.6870E-03**	0.0	3.6811E-03	0.0	3.6969E-03	0.0
			20X+	20	**1.5211E-03**	0.0	1.5187E-03	0.0	1.5252E-03	0.0
			21X+	21	**1.6464E-03**	0.0	1.6437E-03	0.0	1.6508E-03	0.0
			22X+	22	**-2.9810E-02**	0.0	-2.9762E-02	0.0	-2.9890E-02	0.0
			23X+	23	**-2.9069E-02**	0.0	-2.9022E-02	0.0	-2.9147E-02	0.0
			24X+	24	**-2.8565E-02**	0.0	-2.8519E-02	0.0	-2.8642E-02	0.0
			25X+	25	**-4.6575E-02**	0.0	-4.6501E-02	0.0	-4.6701E-02	0.0
		DRIVING-PT COEFFICIENTS:			3.3986E-02	0.0	-1.5917E-02	0.0	-1.6206E-02	0.0

* LARGEST = IC # 1 *

ERAP11 calculates scaled mode shapes for all available driving points (if specified). In this example, results for all 3 driving points are calculated. The scaled mode shape with the largest driving-point amplitude (IC #1 in this example) should be used for best reliability

because it is least affected by measurement noise. The driving point with the largest amplitude is indicated at the bottom of the listing.

These ERAP11 results are now compared with corresponding NASTRAN results in Universal file MMST_NASEIGV_900110_TESTDOFS.UNV, listed below. Bold type highlights the first 25 mode shape components in the x direction, corresponding to the first 25 ERA measurements. (**Note:** The NASTRAN mode shape uses NASTRAN grid point numbers as follows: grid pt. 40, x direction = ERA measurement no. 1, grid pt. 41, x direction = ERA measurement no. 2, etc.) The error between the ERA and NASTRAN mass-scaled mode shapes is negligible (approximately 0.5%).

```
    -1
    55
GET OUTPUT2 FILE OF EIGENVECTORS
GRID POINT DISPLACEMENTS
ANALYSIS DATE  1/10/90
REAL EIGENVALUE SOLUTION
MODE SHAPE        128 FREQUENCY  4.22221E+01
          1          2          3          8          2          6
          2          4          1        128          0          0          0          0
  0.42222E+02  0.10000E+01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
       40
  0.99236E-01  0.36341E-01 -0.17377E-02 -0.11193E-01  0.28707E-01 -0.96999E-01
       41
  0.94043E-01  0.33838E-01 -0.46246E-02 -0.14773E-01  0.24446E-01  0.36449E-01
       42
  0.94835E-01  0.37376E-01  0.10874E-01 -0.13058E-01  0.21486E-01  0.51143E-01
       58
  0.11982E+00  0.46000E-01 -0.33082E-03 -0.25991E-02  0.96796E-02 -0.80421E-01
       59
  0.11740E+00  0.45803E-01 -0.39250E-03 -0.35698E-02  0.10389E-01  0.11208E+00
       60
  0.11583E+00  0.49013E-01  0.70776E-02 -0.31021E-02  0.11325E-01 -0.39228E-01
       76
  0.12984E+00  0.47530E-01  0.36538E-02  0.19462E-02 -0.56527E-03 -0.12636E+00
       77
  0.12288E+00  0.44169E-01  0.44314E-02  0.14408E-02 -0.25739E-02  0.45816E-01
       78
  0.12392E+00  0.48962E-01  0.29386E-03 -0.55089E-03 -0.27826E-02  0.68085E-01
       94
  0.11465E+00  0.44500E-01  0.75005E-02  0.36886E-02 -0.17618E-01 -0.76553E-01
       95
  1.11800E-01  4.39980E-02  9.69940E-03  3.09190E-03 -1.73590E-02  1.05990E-01
       96
  1.10310E-01  4.76960E-02 -6.90540E-03  6.57300E-03 -1.41210E-02 -3.79410E-02
      112
  8.79500E-02  3.20240E-02  9.59100E-03  1.59600E-02 -2.48160E-02 -8.64330E-02
      113
  8.23320E-02  2.92190E-02  1.45590E-02  1.38570E-02 -2.43170E-02  3.04550E-02
      114
  8.30220E-02  3.35210E-02 -1.21230E-02  9.96460E-03 -2.60510E-02  4.55610E-02
```

```
     130
 4.56300E-02  1.60980E-02  1.23510E-02  7.42340E-03 -3.44800E-02 -3.27290E-02
     131
 4.40940E-02  1.56780E-02  1.54000E-02  7.51420E-03 -3.36900E-02  4.22450E-02
     132
 4.35150E-02  1.75750E-02 -1.37910E-02  1.25850E-02 -2.85850E-02 -1.39460E-02
     148
 3.71660E-03  1.05280E-03  1.04160E-02  1.75120E-02 -2.70390E-02 -7.88520E-03
     149
 1.79270E-03 -5.73130E-05  1.51370E-02  1.46520E-02 -2.64340E-02  1.84070E-03
     150
 1.80440E-03  2.10160E-03 -1.01500E-02  1.08160E-02 -2.74140E-02  1.88530E-03
     166
-2.99410E-02 -1.60580E-02  9.53360E-03  5.10310E-03 -2.26450E-02  8.16030E-03
     167
-2.89990E-02 -1.57780E-02  9.09590E-03  8.16730E-03 -2.09150E-02 -2.42630E-02
     168
-2.85730E-02 -1.70890E-02 -1.40810E-03  9.20700E-03 -1.62140E-02  1.88830E-02
     184
-4.67830E-02 -1.70250E-02  3.82790E-03  5.54580E-04  5.26470E-03 -1.30280E-03
```

3.16 Reconstruction

Two post-processors are available for "reconstruction," i.e., calculation of IRFs (for continuous-time models) or PRFs (for discrete-time models) using ERA identification results. In structural modal-identification applications, reconstructed FRFs (Fourier transform of IRFs) are often compared with corresponding experimental FRFs. Additional comparisons may also be made of reconstructed FRFs containing individual modes or groups of modes in order to examine individual contributions. Good agreement of reconstructed functions with corresponding measurements is a necessary, **but not sufficient**, condition of accurate structural modal identification.[143] Responses due to other, general, input time histories may also be predicted using an ERA-identified model, and this process is also sometimes called "reconstruction" or simply "response prediction."

Program ERAP10 calculates IRFs using a continuous model representation and program ERAP10B calculates PRFs using a discrete model representation.[144] Both programs read ERA results from the Tape79 output file (MATRIXx ASCII format). Tape79 is activated by including an ITAPES=79 statement in Field 4 of the ERA User Input file. By default, Tape79 is deactivated. These programs write the reconstructed functions to an output file in Tape1 format.

---

[143]When [A,B,C,D] is used for control design (modal parameters are not of interest), good agreement of predicted and measured responses may be a sufficient condition as well. Modal-parameter inaccuracy may not affect control design as long as input-output behavior is predicted closely.

[144]ERAP10B can also compute responses due to general inputs. ERAP10 does not currently have this capability. ERAP10B can also compute approximate IRFs.

ERAP10 and ERAP10B are demonstrated in Sections 3.16.1 and 3.16.2, respectively, using the Mini-Mast simulated data. Reconstruction results for the MATLAB 2-DOF example problem were shown previously in Section 2.6.8.

3.16.1 Continuous-Time Reconstruction (ERAP10)

The IRF between response measurement 3 and shaker location 2 is reconstructed from the INIT_20_50 ERA results using GO Input file P10_DEMO.COM. Here is a listing of this file:

```
$! P10_DEMO.COM
$!
$ RUN ERA$EXES:ERAP10
79INIT_20_50      TAPE79 FILENAME
1       1=TIME DOMAIN, 2=FREQ. DOMAIN RECONSTRUCTION
1       WHICH DAMPING TO USE? 1=STD ZETA, 2=ZETA2
-100    FIRST EIGENVALUE TO INCLUDE
1000    LAST EIGENVALUE TO INCLUDE
3       FIRST MEASUREMENT NO. TO RECONSTRUCT
3       LAST MEASUREMENT NO. TO RECONSTRUCT
2       FIRST I.C. TO RECONSTRUCT
2       LAST I.C. TO RECONSTRUCT
1920    NO. OF TIME PTS. TO CALCULATE
1       SHOULD ZERO BE USED IF ZETA < 0 WAS IDENTIFIED?  1=YES
0       SHOULD D MATRIX/DT BE ADDED TO INITIAL TIME SAMPLES ? 1=YES
1       SAVE INDIVIDUAL MODAL TIME HISTORIES?  1=YES
1       ARE THE INCLUDE FLAGS O.K. ?  1=YES
```

Copy this file into your working directory and execute it using GO:

```
COPY ERA$GO:P10_DEMO.COM []

GO P10_DEMO
```

The following information appears on your computer screen when P10_DEMO is run:

```
ERAP10.  TIME- OR FREQ.-DOMAIN RECONSTRUCTION,
USING DATA IN MATRIXX FORMAT ON TAPE79.

TAPE79 FILENAME ?  [DEFAULT FILE TYPE = .DAT])
79INIT_20_50.DAT

ENTER RECONSTRUCTION TYPE:  (1)
 1 - TIME-DOMAIN
 2 - FREQUENCY-DOMAIN
          1

WHICH IDENTIFIED DAMPING VALUES SHOULD BE USED ? (1)
 1 = STD. DAMPING FACTORS DERIVED FROM IDENTIFIED EIGENVALUES
 2 = ZETA2, DERIVED USING IDENTIFIED EIGENVECTOR COMPONENTS AT
```

```
      THE BEGINNING VS. THE END OF THE DATA ANALYSIS WINDOW
          1

NCASES ..........................    1

**********************************************************************

SAMPLING FREQUENCY, HZ ............    60.000

FMIN ..............................    20.000
NTIM [NO. OF TIME SAMPLES USED] ...   50
MTIM [TAPE1 RECORD SIZE] .......... 1920
NSKIP .............................    0

NO. OF MEASUREMENTS (OUTPUTS) ..... 104
NO. OF INIT. CONDITIONS (INPUTS) ..   3

IORDER ............................   31

NO. OF   REAL  EIGENVALUES ........   7
NO. OF COMPLEX EIGENVALUES ........  12


* * * REAL EIGENVALUES ARE DESIGNATED WITH NEGATIVE EIGENVALUE NOS. * * *


FIRST EIGENVALUE NO. TO INCLUDE ?  ( -7)
 [ENTER A LARGE NEGATIVE NO. TO INCLUDE ALL]
       -100

LAST EIGENVALUE NO. TO INCLUDE ?  ( 12)
 [ENTER A LARGE POSITIVE NO. TO INCLUDE ALL]
       1000

FIRST MEASUREMENT NO. [OUTPUT NO.] TO RECONSTRUCT ?  (1)
          3

LAST MEASUREMENT NO. [OUTPUT NO.] TO RECONSTRUCT ?  (104)
          3

FIRST INITIAL CONDITION NO. [INPUT NO.] TO RECONSTRUCT ?  (1)
          2

LAST INITIAL CONDITION NO. [INPUT NO.] TO RECONSTRUCT ?  (  3)
          2

NO. OF TIME POINTS TO CALCULATE ?  ( 1920)
       1920

IF NEGATIVE (UNSTABLE) DAMPING WAS IDENTIFIED FOR A MODE,
SHOULD ZERO DAMPING BE USED INSTEAD ?  1 = YES.  (1)
          1
```

```
SHOULD D MATRIX/DT BE ADDED TO INITIAL TIME SAMPLES ? 1=YES  (0)
          0

SAVE INDIVIDUAL MODAL TIME HISTORIES, AS WELL AS THE
OVERALL RECONSTRUCTED TIME HISTORY ?  1 = YES.  (0)
          1


*** THE OVERALL RECONSTRUCTION WILL BE WRITTEN IN TAPE1 FORMAT
    TO FOR031 FOR I.C. #1, FOR032 FOR I.C. #2, ETC.


*** THE INDIVIDUAL (PER MODE) RECONSTRUCTIONS WILL BE WRITTEN IN TAPE1 FORMAT
    TO FOR041 FOR I.C. #1, FOR042 FOR I.C. #2, ETC.



IF INCLUDE_FLAG=1, THE CORRESPONDING EIGENVALUE WILL BE INCLUDED IN THE
RECONSTRUCTION. TO SKIP ANY OF THE FOLLOWING EIGENVALUES, SET ITS
INCLUDE_FLAG TO ZERO :

 E.V. NO.   INCLUDE_FLAG
 --------   ------------

   REAL EIGENVALUES:
                        FD, HZ    SIGMA, RAD/SEC     TIME CONSTANT, SEC

    -1  ------>  1      20.000          0.48             -2.0751
    -2  ------>  1      20.000        -24.46              0.0409
    -3  ------>  1      20.000        -96.80              0.0103
    -4  ------>  1      50.000        -80.55              0.0124
    -5  ------>  1      50.000        -57.79              0.0173
    -6  ------>  1      50.000        -21.79              0.0459
    -7  ------>  1      50.000         -7.49              0.1334

 COMPLEX EIGENVALUES:
                        FD, HZ       ZETA,%    ZETA2,%      CMI, %

     1  ------>  1     20.013         8.078     4.466        0.00
     2  ------>  1     20.303        48.674     6.241        0.00
     3  ------>  1     21.571*        0.906     0.930       93.67*
     4  ------>  1     23.536         1.168     0.992       57.14
     5  ------>  1     28.628         1.109     1.018       74.14
     6  ------>  1     30.717**       0.992     0.990       97.35**
     7  ------>  1     32.069**       1.002     1.005       96.29**
     8  ------>  1     36.908         3.482     1.504        0.01
     9  ------>  1     39.005*        1.022     1.022       92.52*
    10  ------>  1     42.227**       1.003     0.998       95.17**
    11  ------>  1     44.860*        0.971     0.989       92.47*
    12  ------>  1     49.701        34.119     1.990        0.00

ARE THE INCLUDE_FLAGS O.K. ?  1=YES  (1)
          1
```

```
NEGATIVE DAMPING WAS IDENTIFIED FOR EIGENVALUE NO.  -1.
 CHANGED TO ZERO FOR RECONSTRUCTION.

NI, NS, E.V. NO., IREC40() =     2     3    -1     1
NI, NS, E.V. NO., IREC40() =     2     3    -2     2
NI, NS, E.V. NO., IREC40() =     2     3    -3     3
NI, NS, E.V. NO., IREC40() =     2     3    -4     4
NI, NS, E.V. NO., IREC40() =     2     3    -5     5
NI, NS, E.V. NO., IREC40() =     2     3    -6     6
NI, NS, E.V. NO., IREC40() =     2     3    -7     7
NI, NS, E.V. NO., IREC40() =     2     3     1     8
NI, NS, E.V. NO., IREC40() =     2     3     2     9
NI, NS, E.V. NO., IREC40() =     2     3     3    10
NI, NS, E.V. NO., IREC40() =     2     3     4    11
NI, NS, E.V. NO., IREC40() =     2     3     5    12
NI, NS, E.V. NO., IREC40() =     2     3     6    13
NI, NS, E.V. NO., IREC40() =     2     3     7    14
NI, NS, E.V. NO., IREC40() =     2     3     8    15
NI, NS, E.V. NO., IREC40() =     2     3     9    16
NI, NS, E.V. NO., IREC40() =     2     3    10    17
NI, NS, E.V. NO., IREC40() =     2     3    11    18
NI, NS, E.V. NO., IREC40() =     2     3    12    19
NI,NS,IREC30() =     2     3     1

*** THE OVERALL RECONSTRUCTION IS WRITTEN IN TAPE1 FORMAT
    TO FILE FOR031 FOR I.C. #1, FILE FOR032 FOR I.C. #2, ETC.

*** THE INDIVIDUAL (PER MODE) RECONSTRUCTIONS ARE WRITTEN IN TAPE1 FORMAT
    TO FILE FOR041 FOR I.C. #1, FILE FOR042 FOR I.C. #2, ETC.
```

Two output files are generated by ERAP10 as described in the text immediately above. In this demonstration, an IRF for Input (initial condition) #2 is calculated. Therefore, the output files are named FOR032 and FOR042. File FOR032 contains the overall IRF (i.e., the IRF constructed by summing all modal components). File FOR042 contains the 19 individual modal components as 19 Tapel data records. Documentation of these components is printed in the ERAP10 output (see listing above). In this example, ERA identified 7 real eigenvalues and 12 complex-conjugate pairs of eigenvalues (modes) for a total of 19 modal components.

Enter the following DIRECTORY command to see the files generated by P10_DEMO.COM:

```
$ DIRECTORY/SIZE FOR*

Directory SDBRP$DKA0:[PAPPA.DEMO]

FOR032.DAT;1              16   1-MAR-1994 10:41:29.67  [PAPPA]
FOR042.DAT;1             286   1-MAR-1994 10:41:25.84  [PAPPA]
```

```
Total of 2 files, 302 blocks.
```

Before examining these results, the "measured" data record on file T1_MMST_NAS_SH2_20_50.DAT is combined with the reconstruction results into a single Tape1 file (because program ERAG1 can plot data from only one file). This is accomplished with GO Input files P88_1_DEMO.COM and P88_2_DEMO.COM.

Here is a listing of file P88_1_DEMO.COM:

```
$! P88_1_DEMO.COM
$!
$ RUN ERA$EXES:ERAP88
T1_MMST_NAS_SH2_20_50
FOR032
TEMP
0    WRITE CC FILE?  1=YES
1920 NTIM
3    START RECORD ON 1ST FILE TO COPY
1    NO. OF CONSECUTIVE RECORDS TO COPY
0    NO. OF DATA SAMPLES TO SKIP AT BEGINNING OF EACH RECORD ON 1ST FILE
1    START RECORD ON 2ND FILE TO COPY
1    NO. OF CONSECUTIVE RECORDS TO COPY
0    NO. OF DATA SAMPLES TO SKIP AT BEGINNING OF EACH RECORD ON 2ND FILE
1    NO. OF TIME TO MAKE ALTERNATING READS & WRITES?
```

The following information appears on your computer screen when P88_1_DEMO is run:

```
ERAP88. UTILITY PROGRAM TO INTERLEAVE DATA ON TWO TAPE1 FILES

        (CAN BE USED TO COMBINE DATA & RECONSTRUCTION RESULTS, E.G.,
         FOR OVERLAY PLOTTING WITH ERAG1)

NAME OF 1ST TAPE1 FILE ?  [DEFAULT FILE TYPE = .DAT]
T1_MMST_NAS_SH2_20_50.DAT

NAME OF 2ND TAPE1 FILE ?  [DEFAULT FILE TYPE = .DAT]
FOR032.DAT

NAME FOR OUTPUT TAPE1 FILE ?  [DEFAULT FILE TYPE = .DAT]
TEMP.DAT

WRITE COORDINATE-CODE FILE ALSO?  1=YES  (1)
          0

NTIM ?  ( 1920)
       1920

START RECORD ON 1ST TAPE1 FILE TO COPY ?  (1)
          3
```

```
NO. OF CONSECUTIVE RECORDS TO COPY FROM 1ST FILE BEFORE SWITCHING
TO 2ND FILE ?  (1)
          1

NO. OF SAMPLES TO SKIP AT THE BEGINNING OF EACH
RECORD ON 1ST TAPE1 FILE ?  (0)
          0

START RECORD ON 2ND TAPE1 FILE TO COPY ?  (1)
          1

NO. OF CONSECUTIVE RECORDS TO COPY FROM 2ND FILE BEFORE SWITCHING
BACK TO 1ST FILE ?  (1)
          1

NO. OF SAMPLES TO SKIP AT THE BEGINNING OF EACH
RECORD ON 2ND TAPE1 FILE ?  (0)
          0

NO. OF CONSECUTIVE TIMES TO MAKE THESE ALTERNATING READS & WRITES ?  (10000)
          1

FILE 1: SEARCHING FOR RECORD    3 ...
WROTE REC.      1
WROTE REC.      2

    2 RECORDS WRITTEN TO OUTPUT FILE
    TEMP.DAT
```

Here is a listing of file P88_2_DEMO.COM:

```
$! P88_2_DEMO.COM
$!
$ RUN ERA$EXES:ERAP88
TEMP
FOR042
DATA_VS_RECON
0     WRITE CC FILE?  1=YES
1920 NTIM
1     START RECORD ON 1ST FILE TO COPY
2     NO. OF CONSECUTIVE RECORDS TO COPY
0     NO. OF DATA SAMPLES TO SKIP AT BEGINNING OF EACH RECORD ON 1ST FILE
1     START RECORD ON 2ND FILE TO COPY
100   NO. OF CONSECUTIVE RECORDS TO COPY
0     NO. OF DATA SAMPLES TO SKIP AT BEGINNING OF EACH RECORD ON 2ND FILE
1     NO. OF TIME TO MAKE ALTERNATING READS & WRITES?
```

The following information appears on your computer screen when P88_2_DEMO is run:

```
ERAP88. UTILITY PROGRAM TO INTERLEAVE DATA ON TWO TAPE1 FILES

        (CAN BE USED TO COMBINE DATA & RECONSTRUCTION RESULTS, E.G.,
```

```
         FOR OVERLAY PLOTTING WITH ERAG1)

NAME OF 1ST TAPE1 FILE ?  [DEFAULT FILE TYPE = .DAT]
TEMP.DAT

NAME OF 2ND TAPE1 FILE ?  [DEFAULT FILE TYPE = .DAT]
FOR042.DAT

NAME FOR OUTPUT TAPE1 FILE ?  [DEFAULT FILE TYPE = .DAT]
DATA_VS_RECON.DAT

WRITE COORDINATE-CODE FILE ALSO?  1=YES  (1)
          0

NTIM ?  ( 1920)
       1920

START RECORD ON 1ST TAPE1 FILE TO COPY ?  (1)
          1

NO. OF CONSECUTIVE RECORDS TO COPY FROM 1ST FILE BEFORE SWITCHING
TO 2ND FILE ?  (1)
          2

NO. OF SAMPLES TO SKIP AT THE BEGINNING OF EACH
RECORD ON 1ST TAPE1 FILE ?  (0)
          0

START RECORD ON 2ND TAPE1 FILE TO COPY ?  (1)
          1

NO. OF CONSECUTIVE RECORDS TO COPY FROM 2ND FILE BEFORE SWITCHING
BACK TO 1ST FILE ?  (1)
        100

NO. OF SAMPLES TO SKIP AT THE BEGINNING OF EACH
RECORD ON 2ND TAPE1 FILE ?  (0)
          0

NO. OF CONSECUTIVE TIMES TO MAKE THESE ALTERNATING READS & WRITES ?  (10000)
          1
WROTE REC.      1
WROTE REC.      2
WROTE REC.      3
WROTE REC.      4
WROTE REC.      5
WROTE REC.      6
WROTE REC.      7
WROTE REC.      8
WROTE REC.      9
WROTE REC.     10
WROTE REC.     11
WROTE REC.     12
WROTE REC.     13
```

```
WROTE REC.     14
WROTE REC.     15
WROTE REC.     16
WROTE REC.     17
WROTE REC.     18
WROTE REC.     19
WROTE REC.     20
WROTE REC.     21

END-OF-FILE ENCOUNTERED ON 2ND DATA FILE

   21 RECORDS WRITTEN TO OUTPUT FILE
    DATA_VS_RECON.DAT
```

Data and reconstruction are now compared using GO Input file G1B_P10_DEMO.COM. The comparison is shown in **Fig. 3-24**. The top plots show the "measured" IRF and FRF, and the bottom plots show the reconstructed IRF and FRF. There is negligible difference between the data and reconstruction except near the beginning and end of the FRF.

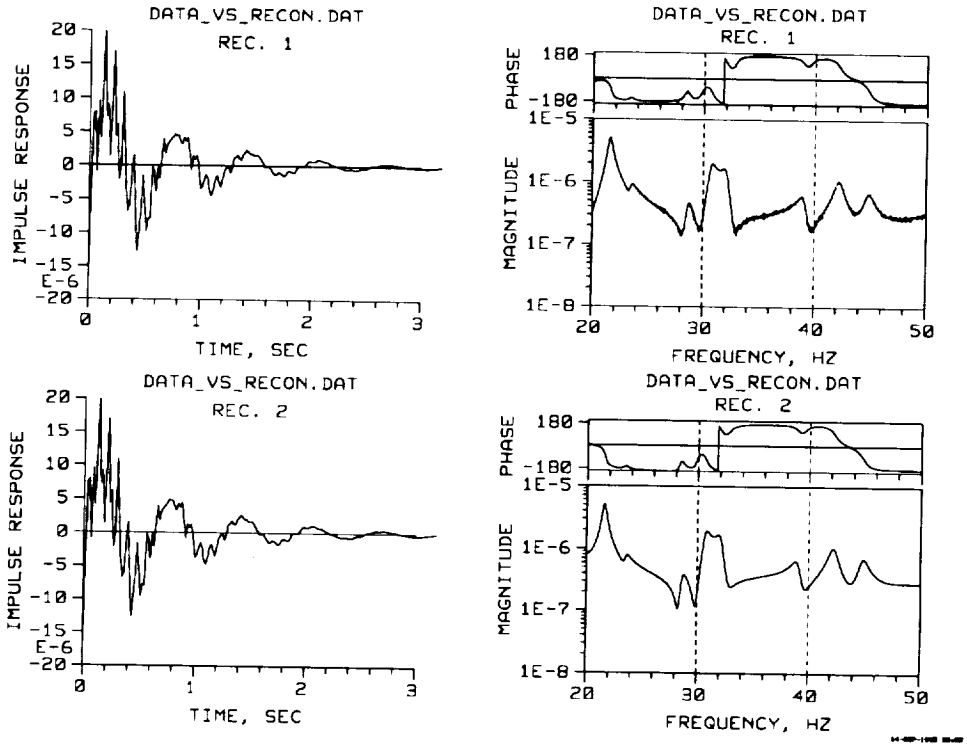


Fig. 3-24. Comparison of Data (Top) With Continuous Time Reconstruction (Bottom) Using ERAP10 [G1B_P10_DEMO]

Next, the individual identified modal components (7 real eigenvalues and 12 complex-conjugate pairs of eigenvalues) are plotted in **Fig. 3-25** together with the total

reconstructed spectrum as a solid line. The total spectrum equals the (complex) summation of the 19 individual modal components. Corresponding phase angle results are not shown.

Fig. 3-25 is generated using GO Input file G1F_P10_DEMO.COM. Copy it into your working directory and execute it as follows:

```
COPY ERA$GO:G1F_P10_DEMO.COM []

GO G1F_P10_DEMO
```

This figure provides a good illustration of the complexity of the modal decomposition (modal identification) process.

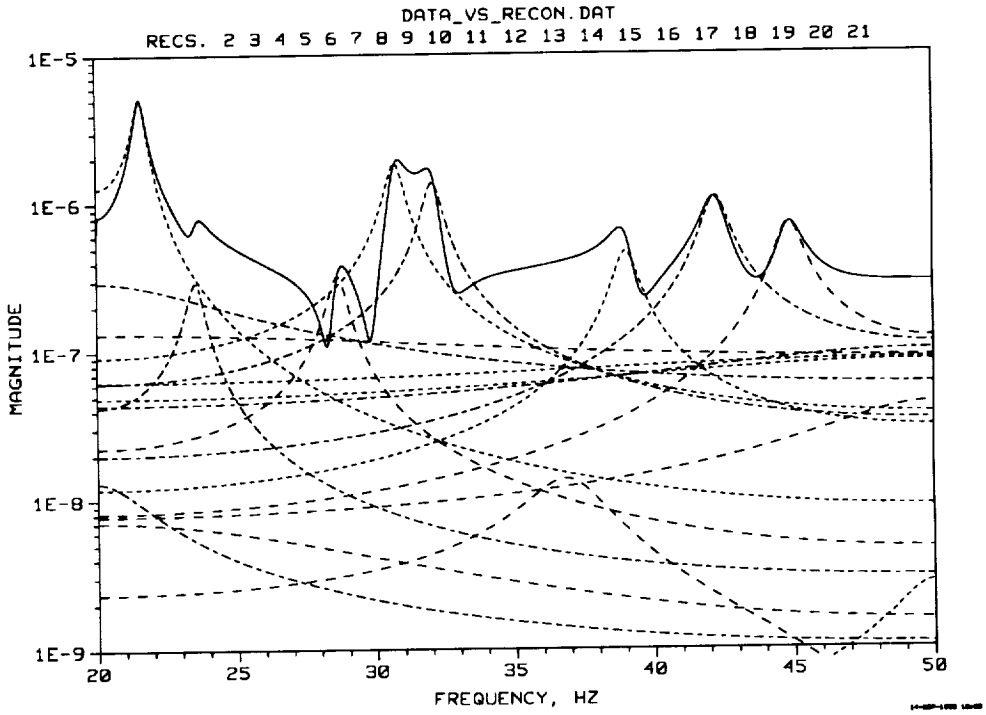


Fig. 3-25. Comparison of Total Reconstructed Spectrum (Solid Line) With Individual Modal Components (Dashed Lines) [G1F_P10_DEMO.COM]

3.16.2 Discrete-Time Reconstruction (ERAP10B)

Program ERAP10B is now demonstrated **assuming** that the data in this demonstration problem are pulse response functions (PRFs) rather than impulse response functions

(IRFs).[145] The formulation of ERA with a discrete-time model (ref. Section 2.4) is used by including a MODELD=2 statement in Field 4 of the User Input file (ref. Chapter 6). The User Input file for this analysis is named INIT_20_50_MODELD.ERA. Here is a listing of this file:

```
$! INIT_20_50_MODELD.ERA
$!
$! INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  [PAPPA.DEMO]
$ DEFINE ERA_OUTPUT$ [PAPPA.DEMO]
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=INIT_20_50_MODELD
$!
$ INPUT1:=_MMST_NAS_SH1_20_50
$ INPUT2:=_MMST_NAS_SH2_20_50
$ INPUT3:=_MMST_NAS_SH3_20_50
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=81/
S/MRH=/MRH=520/
S/MIC=/MIC=3/
S/MST=/MST=104/
S/MTIM=/MTIM=1920/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=60.,FMIN=20.
 MODELD=2
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!            [ALWAYS USE EXACTLY 5 LINES]
$!
```

[145]IRFs and PRFs are both free-response functions so that ERA data assumptions are not violated. Of course, the ERA results are not a valid discrete-time model of the system because actual PRFs are not used. This assumption is made to avoid having to generate additional Tape1 files in order to demonstrate program ERAP10B.

```
LINE 1 FOR COMMENTS
INITIAL ANALYSIS OF SIMULATED MINI-MAST DATA
FILTERED DATA: 20 - 50 HZ
USING DEFAULT S.V. CUTOFF.  MODELD=2
INIT_20_50_MODELD:
```

Copy this file into your working directory as follows:

```
COPY ERA$MMST_NAS:INIT_20_50_MODELD.ERA []
```

Edit the input and output directory names in Field 1. They are currently defined as [PAPPA.DEMO] which will not exist on your computer system. Then, execute the ERA job as follows:

```
ERA INIT_20_50_MODELD
```

This ERA analysis required approximately 48 seconds of CPU time on the author's VAXstation 3100 computer.

Plot the results using the following GO Input files: P10B_DEMO.COM, P88_DISCRETE_DEMO.COM, and G1B_P10B_DEMO.COM.

Here is a listing of file P10B_DEMO.COM:

```
$! P10B_DEMO.COM
$!
$ RUN ERA$EXES:ERAP10B
79INIT_20_50_MODELD     TAPE79 FILE
1      1=COMPUTE PRFS, 2=EXCITATION HISTORIES PROVIDED, 3=COMPUTE IRFS
T1TEMP_DISCRETE         OUTPUT FILE TO RECEIVE COMPUTED RESPONSES (TAPE1 FORMAT)
1      CHANGE ALL NEGATIVE (UNSTABLE) DAMPING VALUES TO 0.0? 1=YES
1      PRINT OUT Z-PLANE EVALUES? 1=YES
0      COMPARE CALCULATED RESPONSES WITH MEASURED RESPONSES (RMS) ?  1=YES
1      FIRST CASE TO USE
1      LAST CASE TO USE
1      STEP CASE TO USE
1920   NO. OF TIME PTS. TO CALCULATE
2      FIRST EXCIT. (INPUT) TO USE
2      LAST  EXCIT. (INPUT) TO USE
3      FIRST RESPONSE NO. (OUTPUT) TO USE
3      LAST  RESPONSE NO. (OUTPUT) TO USE
1      PRINT OUT MODAL FREQS, ZETAPS, ETC? 1=YES
1      FIRST MODE TO INCLUDE IN CALCULATION
1000   LAST  MODE TO INCLUDE IN CALCULATION
1      INCLUDE THESE MODES SIMULTANEOUSLY(1) OR INDIVIDUALLY(2) ?
1      OUTPUT DATA PARSING FACTOR. 1=WRITE EVERY DATA PT, 2=WRITE EVERY 2ND
```

The following information appears on your computer screen when P10B_DEMO is run:

```
ERAP10B. SIMULATION OF DISCRETE-TIME LINEAR SYSTEMS WITH ARBITRARY
INPUTS.  USES [Z_EVALUES,BDMODAL,CDMODAL,DDMODAL] FROM TAPE79.
  SOLVES:   X(N+1) = AX(N) + BU(N)
              Y(N) = CX(N) + DU(N)
 *** ASSUMING BLOCK DIAGONAL A MATRIX ***

TAPE79 FILENAME ?  [DEFAULT FILE TYPE = .DAT]
79INIT_20_50_MODELD.DAT

CHOOSE ONE:  (2)
 1. COMPUTE PULSE RESPONSE
 2. EXCITATION HISTORIES PROVIDED
 3. COMPUTE APPROX. IMPULSE RESPONSE (NORMALIZED PULSE RESPONSE)
          1

TAPE1 FILENAME FOR WRITING OUTPUT DATA ? [DEFAULT TYPE = .DAT]
T1TEMP_DISCRETE.DAT

CHANGE ALL NEGATIVE (UNSTABLE) DAMPING VALUES TO 0.0? 1=YES (1)
          1

PRINT OUT Z-PLANE EIGENVALUES ? 1=YES (0
          1

WOULD YOU LIKE TO CALCULATE THE AVG. % ERROR
BETWEEN THE CALCULATED RESPONSES AND A SET OF MEASURED
RESPONSES ? 1=YES  (0)
          0

LOOPOP ..........................  0
PAR(1) - PAR(5) ................. -999.0 -999.0 -999.0 -999.0 -999.0
NCASES ..........................    1

FIRST CASE TO USE ?  (1)
          1

LAST CASE TO USE ?  (   1)
          1

STEP CASE TO USE [I.E., DO LOOP INCREMENT] ?  (1)
          1

CASE NO. ............................    1
 NO. OF INIT. CONDITIONS (INPUTS) ....   3
 NO. OF MEASUREMENTS (OUTPUTS) ....... 104
 IORDER ..............................  30
 DT ..................................  0.0167
 NO. OF REAL EIGENVALUES .............  10
 NO. OF PAIRS OF COMPLEX EIGENVALUES .  10


NO. OF TIME POINTS TO CALCULATE ?  ( 1000)
       1920
```

```
FIRST INITIAL CONDITION NO. [INPUT NO.] TO INCLUDE IN CALCULATION ?  (1)
          2

LAST INITIAL CONDITION NO. [INPUT NO.] TO INCLUDE IN CALCULATION ?  ( 3)
          2

FIRST RESPONSE NO. [OUTPUT NO.] TO CONSTRUCT ?  (1)
          3

LAST RESPONSE NO. [OUTPUT NO.] TO CONSTRUCT ?  (104)
          3

PRINT OUT MODAL FREQS, ZETAPS, ETC.? 1=YES  (1)
          1
VARIABLE z_evalues READ FROM TAPE79.

Z_EVALUES :
           REAL       IMAG.      MAG.       PHSD
     1    1.0102     0.0000     1.0102     0.0000
     2    0.8507     0.0000     0.8507     0.0000
     3    0.8361     0.0000     0.8361     0.0000
     4    0.6438     0.0000     0.6438     0.0000
     5    0.3419     0.0000     0.3419     0.0000
     6    0.2535     0.0000     0.2535     0.0000
     7    0.0311     0.0000     0.0311     0.0000
     8   -0.3885     0.0000     0.3885   180.0000
     9   -0.6481     0.0000     0.6481   180.0000
    10   -0.9047     0.0000     0.9047   180.0000
    11    0.9667     0.1607     0.9799     9.4402
    12    0.9667    -0.1607     0.9799    -9.4402
    13    0.9042     0.3538     0.9710    21.3714
    14    0.9042    -0.3538     0.9710   -21.3714
    15    0.5928     0.7614     0.9650    52.0963
    16    0.5928    -0.7614     0.9650   -52.0963
    17    0.4198     0.8726     0.9683    64.3082
    18    0.4198    -0.8726     0.9683   -64.3082
    19    0.2921     0.9216     0.9668    72.4132
    20    0.2921    -0.9216     0.9668   -72.4132
    21   -0.1921     0.8358     0.8576   102.9439
    22   -0.1921    -0.8358     0.8576  -102.9439
    23   -0.3908     0.8764     0.9596   114.0340
    24   -0.3908    -0.8764     0.9596  -114.0340
    25   -0.6569     0.6957     0.9568   133.3562
    26   -0.6569    -0.6957     0.9568  -133.3562
    27   -0.8203     0.4896     0.9553   149.1673
    28   -0.8203    -0.4896     0.9553  -149.1673
    29   -0.4594     0.2697     0.5327   149.5884
    30   -0.4594    -0.2697     0.5327  -149.5884
VARIABLE cd_modal READ FROM TAPE79.
VARIABLE bd_modal READ FROM TAPE79.
VARIABLE dd_modal READ FROM TAPE79.
VARIABLE fd READ FROM TAPE79.
VARIABLE zetap READ FROM TAPE79.
VARIABLE zeta2p READ FROM TAPE79.
```

```
VARIABLE cmi READ FROM TAPE79.
VARIABLE msr READ FROM TAPE79.

NO. OF REAL EIGENVALUES =     10
NO. OF MODES (PAIRS OF COMPLEX EIGENVALUES) =     10 :

FIRST MODE TO INCLUDE IN THE CALCULATION ? (1)
          1

LAST MODE TO INCLUDE IN THE CALCULATION ? [ENTER LARGE NO. FOR ALL]  (  10)
       1000

ONLY    10 MODES ARE AVAILABLE. THIS NUMBER WILL BE USED.

HOW SHOULD RESPONSE BE COMPUTED ? (1)
 1. USING ALL MODES SIMULTANEOUSLY
 2. USING EACH MODE INDIVIDUALLY
          1

OUTPUT DATA PARSING FACTOR ?  (1)
 1 = WRITE OUT EVERY CALCULATED DATA PT.
 2 = WRITE OUT EVERY 2ND CALCULATED DATA PT.
 ETC.
          1

 MODE        FD       ZETAP     ZETA2P      CMI      MSR
  ---        --       -----     ------      ---      ---
    1    21.573       0.897      0.921    94.02    90.10
    2    23.562       1.194      1.039    54.37    10.69
    3    28.683       1.187      1.084    71.32     5.61
    4    30.718       1.001      0.994    98.00    28.10
    5    32.069       1.007      0.993    95.27    20.23
    6    37.157       3.944      1.330     0.02     0.53
    7    39.006       1.010      1.018    93.61     4.95
    8    42.226       0.999      1.001    95.48    11.44
    9    44.861       0.974      0.996    91.27    14.05
   10    44.931      13.267      1.240     0.00     0.54
NT =    100
NT =    200
NT =    300
NT =    400
NT =    500
NT =    600
NT =    700
NT =    800
NT =    900
NT =   1000
NT =   1100
NT =   1200
NT =   1300
NT =   1400
NT =   1500
NT =   1600
NT =   1700
```

```
NT =  1800
NT =  1900
CASE NO.:    1, CONVERTED     1 UNSTABLE EIGENVALUES TO 0.0 DAMPING

FOR CASE NO.    1:
WROTE OUT     1 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1TEMP_DISCRETE.DAT
NTIM =  1920
(OUTPUT DATA PARSING FACTOR =      1)
```

Here is a listing of file P88_DISCRETE_DEMO.COM:

```
$! P88_DISCRETE_DEMO.COM
$!
$ RUN ERA$EXES:ERAP88
T1_MMST_NAS_SH2_20_50
T1TEMP_DISCRETE
DATA_VS_RECON_DISCRETE
0     WRITE CC FILE?  1=YES
1920 NTIM
3     START RECORD ON 1ST FILE TO COPY
1     NO. OF CONSECUTIVE RECORDS TO COPY
0     NO. OF DATA SAMPLES TO SKIP AT BEGINNING OF EACH RECORD ON 1ST FILE
1     START RECORD ON 2ND FILE TO COPY
1     NO. OF CONSECUTIVE RECORDS TO COPY
0     NO. OF DATA SAMPLES TO SKIP AT BEGINNING OF EACH RECORD ON 2ND FILE
1     NO. OF TIME TO MAKE ALTERNATING READS & WRITES?
```

The following information appears on your computer screen when P88_DISCRETE_DEMO is run:

```
ERAP88. UTILITY PROGRAM TO INTERLEAVE DATA ON TWO TAPE1 FILES

         (CAN BE USED TO COMBINE DATA & RECONSTRUCTION RESULTS, E.G.,
          FOR OVERLAY PLOTTING WITH ERAG1)

NAME OF 1ST TAPE1 FILE ?  [DEFAULT FILE TYPE = .DAT]
T1_MMST_NAS_SH2_20_50.DAT

NAME OF 2ND TAPE1 FILE ?  [DEFAULT FILE TYPE = .DAT]
T1TEMP_DISCRETE.DAT

NAME FOR OUTPUT TAPE1 FILE ?  [DEFAULT FILE TYPE = .DAT]
DATA_VS_RECON_DISCRETE.DAT

WRITE COORDINATE-CODE FILE ALSO?  1=YES  (1)
           0

NTIM ?  ( 1920)
       1920

START RECORD ON 1ST TAPE1 FILE TO COPY ?  (1)
```

```
          3

NO. OF CONSECUTIVE RECORDS TO COPY FROM 1ST FILE BEFORE SWITCHING
TO 2ND FILE ?  (1)
          1

NO. OF SAMPLES TO SKIP AT THE BEGINNING OF EACH
RECORD ON 1ST TAPE1 FILE ?  (0)
          0

START RECORD ON 2ND TAPE1 FILE TO COPY ?  (1)
          1

NO. OF CONSECUTIVE RECORDS TO COPY FROM 2ND FILE BEFORE SWITCHING
BACK TO 1ST FILE ?  (1)
          1

NO. OF SAMPLES TO SKIP AT THE BEGINNING OF EACH
RECORD ON 2ND TAPE1 FILE ?  (0)
          0

NO. OF CONSECUTIVE TIMES TO MAKE THESE ALTERNATING READS & WRITES ?  (10000)
          1

FILE 1: SEARCHING FOR RECORD    3 ...
WROTE REC.      1
WROTE REC.      2

    2 RECORDS WRITTEN TO OUTPUT FILE
    DATA_VS_RECON_DISCRETE.DAT
```

These results are plotted with GO Input file G1B_P10B_DEMO.COM, see **Fig. 3-26**. There is again negligible difference between data and reconstruction except near the beginning and end of the FRF.

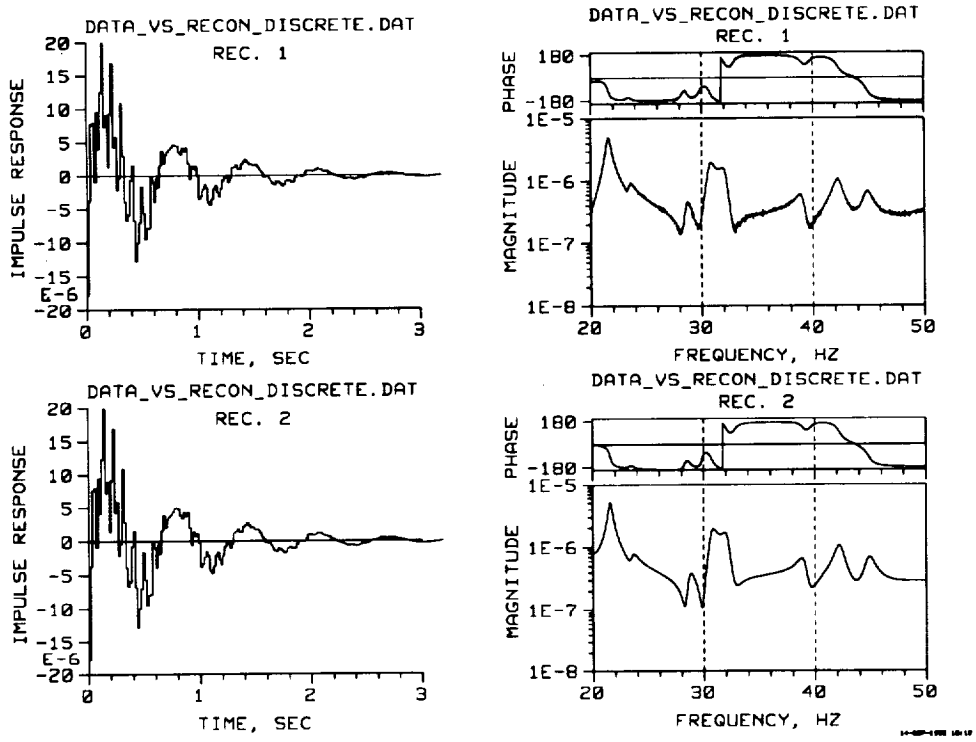


Fig. 3-26. Comparison of Data (Top) With Discrete Time Reconstruction (Bottom) Using ERAP10B [G1B_P10B_DEMO.COM]

4.0 INPUT FILES

ERA uses 3 types of input files as follows:

1. Binary time-history data files referred to as ERA **Tape1 files**.

2. Corresponding ASCII **Coordinate-Code files**.

3. An ASCII **User Input file** containing all job control information.

The User Input file and Tape1 file(s) are required in every run. The Coordinate-Code file(s) is expected by default but can be avoided by specifying a non-zero value for analysis parameter MIDOPT.[146] MIDOPT is an acronym for "Measurement IDentification OPTion."

The format of each input file is described in the remainder of this chapter. The selection of appropriate file names is also discussed. Although these file-naming conventions are not (entirely) mandatory, their use is highly recommended.

4.1 Tape1 Files

All time-history data for ERA is stored in a simple binary format referred to as "ERA Tape1 format." The terminology "Tape1" is a carry-over from use of this software on CDC computers where the default file name for FORTRAN logical unit 1 is TAPE1. To maintain compatibility with previous data sets, this is the *only* data format that can be read.

Tape1 files contain only *time-domain free response data* (or equivalent, including impulse response functions, pulse response function, randomdec signatures, or correlation functions), ref. Section 1.4. There are no provisions for storing other types of data such as frequency-domain functions or input and output time histories. You must convert such data to Tape1 format prior to running the software. Several pre-processors are available to perform the necessary conversions from common data sources, such as program ERAP2 which converts frequency response functions (FRFs) stored in SDRC Type 58 Universal File format. ERAP2 generates impulse response functions in Tape1 format by inverse Fourier transformation of the FRFs. Also available are pre-processors ERAP2B, ERAP75B, and ERAP76B which convert time histories in SDRC Universal files, MATRIXx ASCII files, and MATLAB binary files, respectively, to Tape1 format.[147] Chapter 8 describes the use of pre- and post-processors. Program ERAP2 is demonstrated in Section 3.1.

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[146] All analysis parameters are described in Chapter 6.

[147] Program ERAP76B can only read MATLAB binary files written on a VAX computer.

Users usually use an existing pre-processor to convert their data to Tape1 format. As mentioned above, programs are available to convert data stored as either SDRC Universal files, MATRIXx ASCII files, or MATLAB ASCII or binary files. If your data is stored in another format, you will need to write your own conversion routine. (Do not modify the ERA source code to read other formats. The data input process is not entirely straightforward.) In addition to writing the Tape1 data files, you will also generally want to write corresponding Coordinate-Code files. It is easy to write the necessary conversion routines because the Tape1 and Coordinate-Code file formats are very simple, as discussed below.

The ERA Tape1 format is as follows. If response data for NIC inputs (initial conditions), NST outputs (response measurements), and NTIM time samples are contained in array DATA, they can be stored on disk in Tape1 format using the following FORTRAN statements:[148]

```
      DIMENSION DATA(NIC,NST,NTIM)
C
      DO 10 NI = 1,NIC
      DO 10 NS = 1,NST
      WRITE(NI) (DATA(NI,NS,NT),NT=1,NTIM)
   10 CONTINUE
```

Note that the data for each input (initial condition) is stored in a separate file. Each file must be identical in size and structure, containing response histories arranged in the same sequence as in the accompanying files. By default, the Tape1 files will be named FOR001.DAT, FOR002.DAT, ..., FORnic.DAT if you write data to FORTRAN logical units 1, 2, etc. without specifying a file name using an OPEN statement. However, you cannot use these default names for Tape1 files. *File names beginning with the letters "T1" must be selected instead, as described below.*

Tape1 files contain only data samples. All characteristics of the data (except coordinate codes, which are stored in Coordinate-Code files) must be recorded separately by the user.[149] To run ERA, the data sampling frequency (parameter SF), the number of time points in each record (NTIM), the number of records in each file (NST), and (if nonzero) the lower frequency of "zoom transformed" data (FMIN), are entered in a User

[148]The use of a 3-dimensional array (DATA) here is for illustration purposes only. In application programs, a 1-dimensional array DATA(NTIM) is normally sufficient because only one time history is read (or written) at a time and then it is plotted or otherwise used before the next time history is read (or written).

[149]This information is typically recorded by the author in a file named T1FILES.LIS. This documentation file is kept in the same directory as the associated Tape1 data files.

Input file.[150] Also, a brief description of the test is entered as 5 lines of comments. This information characterizes the Tape1 files. After these parameters and comments are recorded once in a User Input file, additional analyses can be performed quickly by copying and editing this initial file. In situations requiring a more detailed description of the data and/or analyses, you must record this information elsewhere, for example, in an log file.

The data in Tape1 files is stored in a *binary (unformatted)* manner. This approach maintains full data precision at minimum file length. Binary files, however, cannot be printed or edited like ASCII text. Nor can they be moved between unlike computers. Several utility programs are available for these purposes, including ERAP0 to generate listings and ERAP81 to convert Tape1 data to transportable ASCII format. ERAG1 plots Tape1 data files in a variety of time- and frequency-domain formats. Program ERAG1 is demonstrated in Section 3.2.

If you write a new routine to generate Tape1 files, be sure that the data are written on disk as ***single-precision*** *data.* There are no provisions for reading double-precision data with ERA. It is wasteful to use double-precision format for storing experimental data which contain at best 4 or 5 significant decimal digits.

Tape1 file names must begin with the letters "T1", with file type ".DAT". That is, file names of the form T1fname.DAT must be used, where "fname" is any desired string of characters.[151] To associate groups of files generated in the same multiple-input/multiple-output test, file names such as T1TEST1_SH1.DAT, T1TEST1_SH2.DAT, and T1TEST1_SH3.DAT (for Shakers 1, 2, and 3, respectively) are often used.

4.2 Coordinate-Code Files

Coordinate codes are labels such as 1X+, 5Y-, or 27Z+ used to describe physical degrees-of-freedom on a structure. They identify the location and direction, including polarity, of each response measurement. In tests using point excitation sources, they can refer to excitation locations and directions as well. This information is used for plotting identified mode shapes as structural deformation patterns, for correlating identification results with analytical predictions, etc. The X, Y, and Z directions in coordinate codes are global, translational directions. Recently, the use of U, V, and W for rotational degrees-of-freedom

[150] If necessary, NTIM and NST can be recovered from the Tape1 file by running program ERAP0, then entering 0 (the default) after specifying the Tape1 file name.

[151] This naming convention simplifies locating ERA Tape1 files. The convention is enforced by having users specify only the suffices of the Tape1 file names (e.g., "fname" in T1fname.DAT) in the User Input file. "fname" is often selected to be the same as or similar to JOBNAME entered in Field 2 of the User Input file.

was added. This capability, however, is only partially implemented in the current release of the software.

Pre-processors ERAP2 and ERAP2B generate Coordinate-Code files automatically when SDRC Universal files are converted to Tape1 format. When you use these programs, you do not have to be concerned with the format information discussed below. You should, however, be aware of the file naming convention used for Coordinate-Code files described in the closing paragraph.

ERA Coordinate-Code files are ASCII files containing coordinate-code information for each data record in corresponding Tape1 files. They consist of five columns of integers. Column 1 is a record counter ranging from 1 to NST, the total number of records in the Tape1 file. Columns 2 and 3 identify the excitation (input) location and direction of the corresponding data record,[152] where direction is specified using +/-1, +/-2, and +/-3 for directions +/-X, +/-Y, and +/-Z, respectively[153]. Columns 4 and 5 contain similar information for response (output) locations and directions.

As an example, sample Coordinate-Code files for inputs 101X+ and 103Z- are printed below. Each file contains 17 lines of data which identify the 17 data records stored in corresponding Tape1 files. Note that the input location and direction, columns 2 and 3, must be constant throughout the entire file.[154] Also, the response degrees-of-freedom, columns 4 and 5, must appear in identical order in the two separate files if they are to be analyzed simultaneously with ERA.[155] The response degrees-of-freedom can be arranged in any numerical order. Coordinate-Code files are usually written using FORTRAN 5I10 format, although all that is necessary is one or more spaces or a comma between entries on each line (FORTRAN free-field format). *Location numbers appearing in coordinate codes can be up to six digits in length.*

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[152]With free decay data, the input coordinate codes are typically meaningless. However, you must still enter a valid input location and direction in the Coordinate-Code files (although they are not used). Input codes of 1X+, 2X+, etc. are often used for initial condition #1, initial condition #2, etc., although any valid coordinate code is permitted. Each initial condition must have a different input coordinate code if they are to be analyzed simultaneously with ERA.

[153]Rotational degrees-of-freedom can also be specified in Coordinate-Code files using +/-4, +/-5, and +/-6 to refer to +/-U, +/-V, and +/-W. *However, this capability is not yet fully supported.*

[154]This format is of course wasteful. It was implemented in this manner to support future versions of the software that may allow all Tape1 data to be stored in a single file.

[155]ERA typically uses data for 2 or more input locations simultaneously to efficiently identify closely spaced modes.

Sample Coordinate-Code File for Input 101X+ (NST=17)

1	101	1	1	1
2	101	1	2	1
3	101	1	3	1
4	101	1	4	1
5	101	1	5	1
6	101	1	35	-3
7	101	1	33	-3
8	101	1	31	-3
9	101	1	100029	-3
10	101	1	100027	-3
11	101	1	1	2
12	101	1	2	2
13	101	1	3	2
14	101	1	30017	3
15	101	1	30017	1
16	101	1	101	1
17	101	1	103	-3

Corresponding Coordinate-Code File for Input 103Z-

1	103	-3	1	1
2	103	-3	2	1
3	103	-3	3	1
4	103	-3	4	1
5	103	-3	5	1
6	103	-3	35	-3
7	103	-3	33	-3
8	103	-3	31	-3
9	103	-3	100029	-3
10	103	-3	100027	-3
11	103	-3	1	2
12	103	-3	2	2
13	103	-3	3	2
14	103	-3	30017	3
15	103	-3	30017	1
16	103	-3	101	1
17	103	-3	103	-3

ERA will look for Coordinate-Code file(s) by default (signified by analysis parameter MIDOPT = 0). In simple problems where coordinate codes are unimportant, or in problems where Tape1 files contain consecutively numbered measurements, Coordinate-Code files can be avoided. This is accomplished by specifying a non-zero value for parameter MIDOPT in Field 4 of the User Input file. Several non-zero MIDOPT options are available. See Chapter 6 for details.

Each Coordinate-Code file is associated with a particular Tape1 file. *This association is established by using similar file names, as follows.* Coordinate-Code files

must have the same name as the corresponding Tape1 data file except with the initial "T1" changed to "TC". For example, the Coordinate-Code file for a Tape1 file named T1TEST1_SH1.DAT must be TCTEST1_SH1.DAT.

4.3 User Input File

All job-control information for running ERA is placed into a single file known as the User Input File. New User Input files are constructed by copying and editing existing ones such as file MIMO1.ERA listed below.[156] You should name your User Input files FNAME.ERA, where "FNAME" is any string of characters.[157]

Each User Input file contains five fields of data:

1. Input and output directory names.

2. Input and output file names.

3. Array dimensions (= default analysis parameters).

4. All other analysis parameters.

5. A 5-line job description.

A sample User Input file, MIMO1.ERA, is listed below. Notice that each of the five fields of data mentioned above includes one or more lines of comments describing the manner in which the file should be edited. *Do not modify User Input files in any other way. If you do, the automatic editing process invoked by ERA.COM may seriously malfunction.* The five fields of data are discussed individually following the listing.

```
$!  MIMO1.ERA:  USER INPUT FILE FOR MIMO TEST CASE #1
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  [ERA.TESTCASES]
$ DEFINE ERA_OUTPUT$ [ERA.TESTCASES]
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
```

[156]File MIMO1.ERA is stored in directory ERA$TESTCASES. Job MIMO1 is discussed in Section 9.2.1.

[157]"FNAME" is normally selected to be the same as JOBNAME entered in Field 2 of the User Input file. JOBNAME can be no longer than 26 characters.

```
$!
$ JOBNAME:=MIMO1
$!
$ INPUT1:=MIMO1_SH1
$ INPUT2:=MIMO1_SH2
$ INPUT3:=MIMO1_SH3
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=30/
S/MRH=/MRH=300/
S/MIC=/MIC=3/
S/MST=/MST=30/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=100.
 IORDTU=8,MSTO50=1
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!             [ALWAYS USE EXACTLY 5 LINES]
$!
LINE 1 FOR USER-SUPPLIED JOB DESCRIPTION
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
MIMO1: ERA MIMO TEST CASE 1
```

User Input files are *incomplete* VMS command procedures. If executed as is, they would do nothing. When ERA is run, however, the VMS editor is invoked automatically, and the User Input file is merged with a larger command procedure which is then executed. This process is transparent to the user and requires a negligible amount of time to perform. This approach was selected to make the User Input file as simple as possible.

Each of the five fields of data in the User Input file is discussed below. After you have used ERA a while, the comments appearing in the file should be sufficient to remind you of the steps necessary to edit the file.

Warning

You can add as many comments as you like at the beginning of an ERA User Input file (**before** Field 1).[158] However, never add comments anywhere else in the file or the automatic editing process invoked by ERA.COM will seriously malfunction. Also, never use 10 or more consecutive dashes in your comments. That sequence of characters is used by the editor to distinguish the various sections of the file.

4.3.1 Field 1 - Input and Output Directory Names

Field 1 of the User Input file contains directory names from which ERA reads the Tape1 and Coordinate-Code input files, and to which it writes output files. The directory names are entered to the right of `DEFINE ERA_INPUT$` and `DEFINE ERA_OUTPUT$` with at least one space between fields. Directory names are actual names such as DUA0:[ERA.TESTCASES] or equivalent logical names such as ERA$TESTCASES:.[159] To select the default directory, enter an empty pair of square brackets.[160] If you are connected to DECNET, the directories may reside on other computers if the appropriate read and write permissions are established.

Do not modify Field 1 of the User Input file in any way except by entering directory names to the right of `DEFINE ERA_INPUT$` and `DEFINE ERA_OUTPUT$`.

4.3.2 Field 2 - Input and Output File Names

Field 2 of the User Input file specifies the names of the Tape1 (and corresponding Coordinate-Code) input files and the JOBNAME to be used for naming output files.

ERA assumes that all Tape1 file names begin with the letters "T1" and that the corresponding Coordinate-Code files have the same names except beginning with "TC".

---

[158] Comment lines begin with "$!".

[159] Logical names must be terminated with a colon.

[160] **NOTE:** If ERA is executed interactively or as a spawned subprocess using "@ERA" or "SPNERA," the default directory is your current working directory. However, if ERA is executed as a batch job using the "ERA" command, the default directory is your login directory.

Also, both files must be type ".DAT". Dropping the T1 and .DAT, the names of the Tape1 files are entered to the right of INPUT1:=, INPUT2:=, etc.[161] ERA will attempt to read data from NIC (= MIC by default) separate input files. NIC is an acronym for "Number of Initial Conditions." Declare these NIC file names here. If you list more than NIC files, only the first NIC are used. If you list less than NIC files, a fatal error occurs.

By default, ERA generates output files 50JOBNAME.LIS and 85JOBNAME.LIS in every analysis, where JOBNAME is entered to the right of JOBNAME:= in this field. These files are referred to as the "Tape50" and "Tape85" files. Also, files 51JOBNAME.LIS, 55JOBNAME.LIS, 79JOBNAME.DAT, and 88JOBNAME.UNV, referred to as "Tape51," "Tape55," "Tape79," and "Tape88," are generated when requested.[162]

JOBNAME declared in the User Input file can be no longer than 26 characters. Names longer than 26 characters cause a fatal error when attempting to open certain temporary files.

By convention, the corresponding User Input file is also usually named JOBNAME.ERA, although any file name is permitted.

Do not modify Field 2 of the User Input file in any way except by entering job and file names to the right of JOBNAME:=, INPUT1:=, INPUT2:=, etc., as described above. Blank spaces are permitted before or after the ":=" signs. They are ignored.

4.3.3 Field 3 - Array Dimensions

ERA applications range in size from only a single measurement with a few modes to hundreds of measurements with hundreds of modes. To accommodate such large differences in problem size, FORTRAN DIMENSION statements in a small main program are adjusted at the beginning of every run. The editing and recompilation process is

---

[161]ERA typically uses data for 2 or more input locations simultaneously to efficiently identify closely spaced modes.

[162]Output file TapeXX is activated by including an ITAPES=XX statement in Field 4 of the User Input file. Output file TapeXX can be deactivated with an ITAPE(XX)=0 statement. Chapter 5 describes all output files.

performed automatically and is transparent to the user. The array dimensions are specified in this field of the User Input file.

These array dimensions also establish the default values of several key analysis parameters. In particular, variables MCH, MRH, MIC, and MST entered in this field establish the default values of analysis parameters NCH, NRH, NIC, and NST, respectively. The initial "M" in the name denotes "maximum." MCH, for example, is the maximum value that analysis parameter NCH can have during a run without exceeding array dimensions. By default, NCH=MCH, NRH=MRH, NIC=MIC, and NST=MST. An "N" value smaller than the corresponding "M" value can be entered in Field 4 of the User Input file but this is rarely done. "N" values smaller than corresponding "M" values normally occur only in looping analyses, ref. analysis parameter LOOPOP in Chapter 6.

Guidelines for selecting parameters NCH (MCH) and NRH (MRH) appear in Appendix I. NCH and NRH are the total number of columns and rows, respectively, in the ERA generalized Hankel data matrices. Parameters NIC and NST (the number of inputs and outputs, respectively, used in the analysis) are typically just the total number of input and outputs available. If desired, however, a subset of the available measurements can be analyzed.[163]

Parameter MTIM is treated differently. MTIM is the maximum number of time samples in each data record of the Tape1 file(s). However, variable NTIM is *not* set equal to MTIM. NTIM, the actual number of time samples used in the analysis, is computed internally by the ERA program based on values entered for other parameters (including NCH, NRH, NIC, and NST). No method is available for directly specifying NTIM. The value of NTIM is reported on the Tape50 output file. **Recommended procedure is to set MTIM equal to the exact number of time samples stored in each Tape1 data record.**[164] If MTIM is smaller than NTIM, a fatal error occurs and the value of NTIM is printed on Tape50.

Do not modify Field 3 of the User Input file in any way except by entering the five integer values.

4.3.4 Field 4 - All Other Analysis Parameters

All analysis parameters other than the values discussed in the previous section are specified in Field 4 of the User Input file. A complete list of all available analysis parameters is

[163]Subsets of Tape1 data records must be placed in separate Tape1 files before running ERA. Programs ERAP5 and ERAP88 are available for this purpose. Or, NST consecutive data records of the Tape1 files beginning at record NSFRST can be analyzed by including an NSFRST= statement in Field 4 of the User Input file. Subsets of inputs are selected by supplying only the appropriate file names in Field 2.

[164]Each data record of a Tape1 file normally contains the same number of time samples.

printed at the beginning of *every* Tape50 output file. The default value of any analysis parameter (default values are also printed on Tape50) is modified by entering the name, an equal sign, and the desired value, in this field (FORTRAN NAMELIST format). *Each line in this field must begin with a blank space.* Multiple parameters separated by commas can be entered on each line. The parameters can appear in any alphabetical order.

Some parameters, such as KEYDTA, are arrays.[165] If you do not specify an index, data is placed into the array beginning at the first element, e.g., at KEYDTA(1). Data can be placed into other elements of the array by providing a starting index. For example, KEYDTA(11)=3,7,10 results in KEYDTA(11)=3, KEYDTA(12)=7, and KEYDTA(13)=10.

Field 4 of the User Input file is read by ERA using a FORTRAN NAMELIST READ statement, which is a free-field read command. Thus, the usual decimal point requirements of FORTRAN for integer and real variables are unnecessary. Data conversion from integer to real format and vice versa is performed based on the declared variable type (i.e., INTEGER for all parameters beginning with the letters I though N and REAL for all others). For example, either "SF=20.0" or "SF=20" is acceptable syntax for specifying a sampling frequency of 20 Hz.

Although NAMELIST is *not* a standard FORTRAN 77 command, it is a feature of most FORTRAN compilers.

4.3.5 Field 5 - A 5-Line Job Description

Field 5 contains a five-line job description. Anything can be entered on the first four lines. **The beginning of the fifth line, however, is treated differently.** If you expect to transfer ERA-identified mode shapes (written on Tape88) to the SDRC TDAS software package for animation and/or plotting, the beginning of line 5 should contain a descriptive job name, followed by a colon. (Additional text can appear to the right of the colon.) This name is normally the JOBNAME entered in Field 2. **This descriptive name will appear on all TDAS mode shape displays.** The descriptive name can be no longer than 20 characters.

[165]Chapter 6 describes all analysis parameters.

5.0 OUTPUT FILES

ERA generates 6 types of output files as follows:

	Generated by default?
Tape50: Summary file.	YES
Tape51: Mode shape printer plots.	NO
Tape55: Detailed EMAC results (for KEYDTA analyses).	NO
Tape79: Identification results in MATRIXx format.[166]	NO
Tape85: One-line-per-eigenvalue summary.	YES
Tape88: Mode shapes in SDRC universal file format.	NO

The terminology "Tape50," "Tape51," etc. is a carry-over from use of this software on CDC computers where the default file name for FORTRAN logical unit n is TAPEn. The actual names assigned to these files are created automatically by the ERA software. The names assigned to Tape50, 51, 55, 79, 85, and 88 are 50JOBNAME.LIS, 51JOBNAME.LIS, 55JOBNAME.LIS, 79JOBNAME.DAT, 85JOBNAME.LIS, and 88JOBNAME.UNV, respectively, where JOBNAME is specified in Field 2 of the ERA User Input file, ref. Section 4.3. All output files are written into directory ERA_OUTPUT$ specified in Field 1 of the User Input file. File type ".LIS" is used for Tape50, 51, 55, and 85 so they can be examined during ERA execution (for a batch or spawned job) using the TYPE command. File types ".DAT" and ".UNV" for Tape79 and 88 are the default values assumed by the MATRIXx and SDRC software.

Tape50 and 85 are generated in every analysis by default. Tape51, 55, 79, and 88 are activated by specifying the corresponding number(s) using the ITAPE() or ITAPES parameters in Field 4 of the ERA User Input file, ref. Chapter 6. The ITAPES parameter is normally used. For example, to generate Tapes 55 and 88 (in addition to the default files, Tape50 and 85) specify ITAPES=55,88 (or ITAPES=88,55). These selections could also be entered individually using array parameter ITAPE as follows: ITAPE(55)=1,ITAPE(88)=1. ITAPE(n)=1 activates TAPEn, and ITAPE(n)=0 deactivates TAPEn. You may occasionally want to deactivate TAPE50 or TAPE85. This is accomplished by specifying ITAPE(50)=0 or ITAPE(85)=0. All warning and fatal error messages are written to Tape50 even when it is "deactivated."

The contents of each output file is described below. A portion of a typical file is printed and discussed.

[166]Tape79 is converted to MATLAB MAT-file format using post-processor ERAP79, see Section 5.4.

5.1 Tape50 - Summary File

See Section 3.6 for a discussion of the Tape50 output file.

5.2 Tape51 - Mode Shape Printer Plots

See Section 3.9.1 for a discussion of the Tape51 output file.

5.3 Tape55 - Detailed EMAC Results

See Section 3.14 for a discussion of the Tape55 output file.

5.4 Tape79 - Output in MATRIXx Format

Tape79 is an ASCII file in MATRIXx format containing identification results. It can be read by MATRIXx or read by MATLAB after conversion to binary .MAT format using program ERAP79. The operation of ERAP79 is illustrated below. See also Section 9.2.2 (test case MIMO2) for additional discussion of Tape79 results in MATLAB.

Only basic results are written on Tape79 by specifying ITAPES=79 in Field 4 of the User Input file. Several other data variables and arrays are added to the file by specifying additional analysis parameters. These additional parameters begin with the letters "MX" (ref. Chapter 6 or the list of analysis parameters at the beginning of every Tape50 output file). Additional data are added to Tape79 when either the MODELD or MODELC parameter is used (ref. Chapter 6).

Tape79 is normally read into MATRIXx or MATLAB and is not directly examined by the user. However, if a new conversion routine is necessary, the format of the Tape79 file is very simple to understand. As an example, here is file 79SISO1.DAT generated by test case SISO1 (ref. Section 9.1.1):

File 79SISO1.DAT

```
loopop          1    1    0(1P,8E16.8)
  0.00000000E+00
par            10    1    0(1P,8E16.8)
 -9.99000000E+02 -9.99000000E+02 -9.99000000E+02 -9.99000000E+02 -9.99000000E+02 -9.99000000E+02 -9.99000000E+02 -9.99000000E+02
 -9.99000000E+02 -9.99000000E+02
ncases          1    1    0(1P,8E16.8)
  1.00000000E+00
icase           1    1    0(1P,8E16.8)
  1.00000000E+00
dt              1    1    0(1P,8E16.8)
  9.99999978E-03
mtim            1    1    0(1P,8E16.8)
  1.02400000E+03
nreval          1    1    0(1P,8E16.8)
  0.00000000E+00
ncmds           1    1    0(1P,8E16.8)
  3.00000000E+00
```

```
ntim          1    1    0(1P,8E16.8)
  5.80000000E+01
sf            1    1    0(1P,8E16.8)
  1.00000000E+02
nst           1    1    0(1P,8E16.8)
  1.00000000E+00
nic           1    1    0(1P,8E16.8)
  1.00000000E+00
nskip         1    1    0(1P,8E16.8)
  0.00000000E+00
iorder        1    1    0(1P,8E16.8)
  6.00000000E+00
fmin          1    1    0(1P,8E16.8)
  0.00000000E+00
modeld        1    1    0(1P,8E16.8)
  0.00000000E+00
s_evalues     6    2    0(1P,8E16.8)
 -6.28319263E-01 -6.28319263E-01 -9.42509472E-01 -9.42509472E-01 -3.77062011E+00 -3.77062011E+00  6.28318596E+01 -6.28318596E+01
  9.42477798E+01 -9.42477798E+01  1.88495575E+02 -1.88495575E+02
measid        2    1    0(1P,8E16.8)
  1.00000000E+00  1.00000000E+00
icid          2    1    0(1P,8E16.8)
  1.00000000E+00  1.00000000E+00
nsdrpt        1    1    0(1P,8E16.8)
  1.00000000E+00
az            6    6    0(1P,8E16.8)
 -3.34841937E-01 -9.09367323E-01 -1.25467002E-01  1.17220208E-01 -7.15368837E-02  8.57750624E-02  9.09367859E-01 -1.94578379E-01
 -8.11082274E-02  1.77762762E-01 -7.14147389E-02 -3.10049895E-02 -1.25466928E-01  8.11088979E-02  5.55475593E-01  7.92712033E-01
  1.84373173E-03  1.81582402E-02 -1.17219619E-01  1.77763239E-01 -7.92712152E-01  5.50969899E-01  7.10507259E-02 -7.57249743E-02
  7.15368688E-02 -7.14149475E-02 -1.84356782E-03  7.10511580E-02  7.61569679E-01  5.90573549E-01  8.57752040E-02  3.10049504E-02
  1.81583557E-02  7.57246837E-02 -5.90573609E-01  8.38682353E-01
z_evalues     6    2    0(1P,8E16.8)
  8.03949654E-01  8.03949654E-01  5.82271397E-01  5.82271397E-01 -2.97582209E-01 -2.97582209E-01  5.84103703E-01 -5.84103703E-01
  8.01427722E-01 -8.01427722E-01  9.15863454E-01 -9.15863454E-01
cc            1    6    0(1P,8E16.8)
  1.31504035E+00  1.79459167E+00  1.26602137E+00  5.68506122E-01 -7.38835216E-01 -5.96262634E-01
bc            6    1    0(1P,8E16.8)
 -1.31503344E+00  1.79459429E+00 -1.26602161E+00  5.68505764E-01 -7.38834202E-01  5.96263826E-01
cc_modal      1    6    0(1P,8E16.8)
 -3.24270546E-01 -6.25375867E-01  2.97886044E-01  9.52516437E-01 -8.49116683E-01 -1.35236156E+00
bc_modal      6    1    0(1P,8E16.8)
  1.26020932E+00 -6.53445840E-01  1.91263866E+00 -5.98149598E-01  2.57502580E+00 -1.91403961E+00
dc_modal      1    1    0(1P,8E16.8)
  0.00000000E+00
fd            3    1    0(1P,8E16.8)
  1.00000010E+01  1.50000000E+01  3.00000019E+01
zetap         3    1    0(1P,8E16.8)
  9.99951065E-01  9.99983609E-01  1.99997580E+00
zeta2p        3    1    0(1P,8E16.8)
  9.99981821E-01  9.99999523E-01  2.00000215E+00
cmi           3    1    0(1P,8E16.8)
  9.99979019E+01  9.99982605E+01  9.99953918E+01
emac          3    1    0(1P,8E16.8)
  9.99979477E+01  9.99983063E+01  9.99954376E+01
mpc_w         3    1    0(1P,8E16.8)
  9.99999542E+01  9.99999542E+01  9.99999542E+01
mpc_u         3    1    0(1P,8E16.8)
  9.99999542E+01  9.99999771E+01  9.99998550E+01
prc           3    1    0(1P,8E16.8)
  9.99999817E+02  9.99999817E+02  9.99999817E+02
aratio        3    1    0(1P,8E16.8)
  7.03371823E-01  5.89893222E-01  1.21047124E-01
recip         3    1    0(1P,8E16.8)
 -9.99000000E+02 -9.99000000E+02 -9.99000000E+02
msr           3    1    0(1P,8E16.8)
  2.66729870E+01  5.03675575E+01  8.18185654E+01
```

All data on Tape79 are single-precision, real, 2-dimensional arrays. Scalar variables are simply 1 x 1 arrays. The first line of the file contains the name of the first variable (loopop) followed by 4 parameters as follows:

Parameter
1. The number of rows in the array.
2. The number of columns in the array.
3. Always 0 (signifies real data).
4. FORTRAN format used to write the array.

The first line of the file is followed by the data written with the specified format (parameter 4 above). In this case, LOOPOP=0. All remaining data arrays are then written in the same manner.

The arrays are written to Tape79 in column-wise order, i.e., column 1 appears first, followed by column 2, etc. For example, here are the contents of the 6 x 2 array named s_evalues:

```
s_evalues =
   -0.6283   62.8319
   -0.6283  -62.8319
   -0.9425   94.2478
   -0.9425  -94.2478
   -3.7706  188.4956
   -3.7706 -188.4956
```

It appears on Tape79 as follows:

```
s_evalues     6    2    0(1P,8E16.8)
 -6.28319263E-01 -6.28319263E-01 -9.42509472E-01 -9.42509472E-01 -3.77062011E+00 -3.77062011E+00  6.28318596E+01 -6.28318596E+01
  9.42477798E+01 -9.42477798E+01  1.88495575E+02 -1.88495575E+02
```

All variables on Tape79 are ERA analysis parameters (ref. Chapter 6), or the names are self-explanatory to a knowledgeable user.

File 79SISO1.DAT is converted to MATLAB .MAT format using post-processor ERAP79 as follows:[167]

```
COPY ERA$GO:P79_SISO1.COM []

GO P79_SISO1
```

Here is a listing of GO Input file P79_SISO1.COM:

```
$! P79_SISO1.COM
$!
$ RUN ERA$EXES:ERAP79
79SISO1.DAT     INPUT TAPE79 FILE NAME
SISO1.MAT       OUTPUT .MAT FILE NAME
```

The following information appears on your computer screen when file P79_SISO1.COM is run:

[167]See Section 9.1.1 for information on running test case SISO1 which generates file 79SISO1.DAT. Chapter 8 describes the operation of pre- and post-processors.

```
ERAP79.  CONVERT TAPE79 FILE (ASCII MATRIXX FORMAT)
         TO BINARY MATLAB .MAT FILE

TAPE79 INPUT FILENAME ?  [DEFAULT FILE TYPE = .DAT])
79SISO1.DAT

MATLAB OUTPUT FILENAME ?  [DEFAULT FILE TYPE = .MAT])
SISO1.MAT

VARIABLE        ROWS     COLS
--------        ----     ----
loopop             1        1
par               10        1
ncases             1        1
icase              1        1
dt                 1        1
mtim               1        1
nreval             1        1
ncmds              1        1
ntim               1        1
sf                 1        1
nst                1        1
nic                1        1
nskip              1        1
iorder             1        1
fmin               1        1
modeld             1        1
s_evalues          6        2
measid             2        1
icid               2        1
nsdrpt             1        1
az                 6        6
z_evalues          6        2
cc                 1        6
bc                 6        1
cc_modal           1        6
bc_modal           6        1
dc_modal           1        1
fd                 3        1
zetap              3        1
zeta2p             3        1
cmi                3        1
emac               3        1
mpc_w              3        1
mpc_u              3        1
prc                3        1
aratio             3        1
recip              3        1
msr                3        1

THESE VARIABLES HAVE BEEN WRITTEN INTO A BINARY MATLAB .MAT FILE NAMED:
SISO1.MAT
```

A binary MATLAB MAT-file named SISO1.MAT is generated by P79_SISO1.COM. **Although file SISO1.MAT is a binary file, it can be transferred to other types of computers and read by MATLAB. This is a standard feature of MATLAB.** The author typically transfers ERAP79-generated files from a VAX computer to a Macintosh with MATLAB.

Users writing new programs that read Tape79 should examine subroutine RTPE79.FOR stored in directory ERA$SOURCES. It extracts any specified variable from a Tape79 file.

5.5 Tape85 - One-Line-Per-Eigenvalue Summary

Tape85 is an ASCII file containing principal identification results in a "one-line-per-eigenvalue" format. **Tape85 is normally read primarily by post-processor ERAG15 and is not directly examined by the user.** Results of looping analyses (ref. LOOPOP in Chapter 6) are plotted this way. Data on Tape85 are also plotted by programs ERAG3 (singular values), ERAG3B (EMAC or CMI), and ERAG7 (frequencies).

Certain contents of Tape85 are printed each job, each case, or each eigenvalue. The specific contents of each section are documented at the beginning of every Tape85 file. The corresponding FORTRAN format statement is also given. Users writing new programs that read Tape85 should examine subroutine RTPE85.FOR stored in directory ERA$SOURCES. It extracts various data from Tape85.

Here are the contents of file 85SISO1.LIS:

File 85SISO1.LIS

```
LINE 1 FOR USER-SUPPLIED JOB DESCRIPTION
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
SISO1: ERA TEST CASE 1 USING SISO

ERA VERSION 931216

PRINTED EACH JOB:
 LOOPOP  PAR1     PAR2     PAR3     PAR4     PAR5 NCASES     *   NSTBOT        SF             FMIN
 FORMAT = /I5,5F8.2,3I7,1P,2E13.5

PRINTED EACH CASE:
 ICASE NCMDS IORDER NCH NRH NIC NST NTIM N1 N2 N3 ISTRIP     FR1FIR       FR2FIR      NSKIP IREFTU  N2LAST N3LAST NSFRST
 FORMAT = /I5,2I6,2X,4I4,I5,3I3,I7,1P,2E13.5,I6,I7,3I7
 ALSO PRINT SINGULAR VALUES
 FORMAT = (10(1P,E13.5):)  FOLLOWED BY A BLANK LINE

PRINTED EACH COMPLEX EIGENVALUE:
ICASE IEVNUM   FD-HZ AST1   ZETA-%       EMAC AST1   ZETA2P-%      RFAMP0      RFPHSD     CCREF   MPC-W  MPC-U MSR AST2 PRC-W  PRC-U
 FORMAT = 2I4,1P,E15.7,A2,1P,E15.7,0P,F8.3,A2,1P,E13.5,1P,E13.5,0P,F9.4,A8,2F7.2,F7.3,A2,2F7.2

   0 -999.00 -999.00 -999.00 -999.00 -999.00       1       0       1  1.00000E+02  0.00000E+00

   1     3     6    20  20    1   1   58  1  1  1       1 -9.99000E+02 -9.99000E+02      0      0     10     10      1
 2.81367E+01  2.68655E+01  1.79295E+01  1.49030E+01  9.00325E+00  8.16205E+00  2.67923E-05  2.37027E-05  1.82789E-05  1.65053E-05
 1.17918E-05  1.04463E-05  9.49154E-06  9.19904E-06  8.86203E-06  8.71058E-06  6.85753E-06  5.94910E-06  0.00000E+00  0.00000E+00

  1   1  1.0000001E+01**  9.9995106E-01  99.998**  9.99982E-01  9.99998E-01  90.0000     1X+ 100.00 100.00 26.673**1000.001000.00
  1   2  1.5000000E+01**  9.9998361E-01  99.998**  1.00000E+00  2.00000E+00 -90.0000     1X+ 100.00 100.00 50.368**1000.001000.00
  1   3  3.0000002E+01**  1.9999758E+00  99.995**  2.00000E+00  5.12340E+00  85.5000     1X+ 100.00 100.00 81.819**1000.001000.00
```

5.6 Tape88 - Mode Shapes in Universal File Format.

Tape88 is an ASCII file containing ERA-identified mode shapes in SDRC Universal file format (Type 55). It can be read by other commercial modal analysis programs that support this format, including the SDRC TDAS and LMS CADA programs. Tape88 data are transferred to other programs normally for animation purposes. *There is currently no capability to animate mode shapes with the ERA software.*

Tape88 is also read by programs ERAP25 (MAC or orthogonality), ERAP26 (various utility functions), ERAP125 (frequency, damping, and MAC), ERAG5 (magnitude and phase mode-shape plots), ERAG10 (frequency vs mode no., usually used with NASTRAN .UNV files), ERAG26 (initial amplitude of IRFS, usually used with NASTRAN .UNV files), and ERAG50 (wireframe mode-shape plots).

The format of .UNV files is described in SDRC documentation (Ref. 9). As an example, here are the contents of file 88INIT_20_50.LIS (partial), generated in Section 3.5:

File 88INIT_20_50.LIS (partial)

```
    -1
    55
 INIT_20_50:           1/  1   20.013 HZ   0.00
MODE SHAPE SCALING: RESIDUES, FOR REF. NO.  0
ON NEXT LINE: ZETAP,ZETAP2,EMAC,MPC-W,MPC-U,MSR
    8.078    4.466    0.000   76.013   31.554    6.867
      203        3       12       13
        1        3        2       12        5        3
        2        6     1001        1
-1.01905E+01  1.25746E+02  6.33801E-02 -3.12349E-02 -3.28181E+00 -8.28811E+00
        1
-3.91543E-07  2.24093E-06  3.06497E-07 -1.84988E-06  0.00000E+00  0.00000E+00
        2
-4.79183E-07 -6.13857E-07  2.27954E-07 -3.44943E-06  0.00000E+00  0.00000E+00
        3
-4.89350E-07 -6.23795E-07  3.83276E-07 -3.27263E-07  0.00000E+00  0.00000E+00
        4
-8.93087E-07  3.06478E-06  5.64433E-07 -3.37632E-06  0.00000E+00  0.00000E+00
        5
-8.01400E-07 -1.13154E-06  6.12528E-07 -5.80440E-06  0.00000E+00  0.00000E+00
        6
-8.30957E-07 -1.04220E-06  5.15685E-07 -8.73357E-07  0.00000E+00  0.00000E+00
        7
-1.12667E-06  3.29462E-06  7.97653E-07 -5.18088E-06  0.00000E+00  0.00000E+00
        8
-1.42959E-06 -1.05126E-06  6.52513E-07 -7.75196E-06  0.00000E+00  0.00000E+00
        9
-1.41572E-06 -1.12596E-06  9.66153E-07 -2.64912E-06  0.00000E+00  0.00000E+00
       10
-1.73340E-06  3.84718E-06  1.10619E-06 -7.16526E-06  0.00000E+00  0.00000E+00
       11
-1.83596E-06 -1.75135E-06  1.03026E-06 -1.04849E-05  0.00000E+00  0.00000E+00
       12
-1.81476E-06 -1.78965E-06  1.19259E-06 -4.01426E-06  0.00000E+00  0.00000E+00
       13
-1.90830E-06  3.40624E-06  1.40047E-06 -9.22784E-06  0.00000E+00  0.00000E+00
       14
-2.47705E-06 -1.82068E-06  1.09102E-06 -1.23489E-05  0.00000E+00  0.00000E+00
       15
-2.43569E-06 -1.92645E-06  1.69297E-06 -6.03983E-06  0.00000E+00  0.00000E+00
       16
-2.42731E-06  3.99287E-06  1.58844E-06 -1.09052E-05  0.00000E+00  0.00000E+00
       17
-2.79531E-06 -2.57645E-06  1.36307E-06 -1.45236E-05  0.00000E+00  0.00000E+00
       18
-2.83845E-06 -2.43900E-06  1.82710E-06 -7.25139E-06  0.00000E+00  0.00000E+00
       19
-2.38114E-06  2.96255E-06  1.75322E-06 -1.20708E-05  0.00000E+00  0.00000E+00
       20
```

```
-3.27979E-06 -2.55752E-06  1.27278E-06 -1.55757E-05  0.00000E+00  0.00000E+00
       21
-3.23159E-06 -2.67499E-06  2.25119E-06 -8.88752E-06  0.00000E+00  0.00000E+00
       22
-2.62729E-06  3.03831E-06  1.70958E-06 -1.27168E-05  0.00000E+00  0.00000E+00
       23
-3.41901E-06 -2.85601E-06  1.32938E-06 -1.64770E-05  0.00000E+00  0.00000E+00
       24
-3.39813E-06 -3.12875E-06  2.14563E-06 -9.08279E-06  0.00000E+00  0.00000E+00
       25
-2.21576E-06  1.67976E-06  1.72758E-06 -1.28460E-05  0.00000E+00  0.00000E+00
       26
-3.41730E-06 -3.42325E-06  1.04210E-06 -1.57989E-05  0.00000E+00  0.00000E+00
       27
-3.41406E-06 -3.49399E-06  2.37802E-06 -9.64398E-06  0.00000E+00  0.00000E+00
       28
-1.63772E-06  1.23275E-06  1.18352E-06 -1.02254E-05  0.00000E+00  0.00000E+00
       29
-2.74497E-06 -3.64241E-06  5.65464E-07 -1.28935E-05  0.00000E+00  0.00000E+00
       30
-2.75685E-06 -3.49058E-06  1.72054E-06 -7.08890E-06  0.00000E+00  0.00000E+00
       31
-7.70408E-07 -1.86202E-07  6.00598E-07 -7.09650E-06  0.00000E+00  0.00000E+00
       32
-2.00775E-06 -3.56335E-06 -4.73769E-08 -9.27119E-06  0.00000E+00  0.00000E+00
       33
-1.94491E-06 -3.74133E-06  1.30859E-06 -5.24783E-06  0.00000E+00  0.00000E+00
       34
-1.55593E-07 -8.12642E-07  1.88396E-08 -4.34172E-06  0.00000E+00  0.00000E+00
       35
-1.19673E-06 -3.77797E-06 -5.84614E-07 -5.81851E-06  0.00000E+00  0.00000E+00
       36
-1.18056E-06 -3.87253E-06  7.05109E-07 -2.64184E-06  0.00000E+00  0.00000E+00
       37
 6.65604E-07 -2.36701E-06 -5.46974E-07 -1.60345E-06  0.00000E+00  0.00000E+00
       38
-6.13635E-07 -3.51276E-06 -1.21111E-06 -2.33196E-06  0.00000E+00  0.00000E+00
       39
-6.41962E-07 -3.35959E-06  1.86207E-07 -8.65132E-07  0.00000E+00  0.00000E+00
       40
 1.13043E-06 -3.23124E-06 -8.86103E-07  4.19240E-07  0.00000E+00  0.00000E+00
       41
-3.29814E-09 -3.55141E-06 -1.55297E-06  1.64888E-07  0.00000E+00  0.00000E+00
       42
-4.90923E-08 -3.43869E-06 -2.74493E-07  5.88077E-07  0.00000E+00  0.00000E+00
       43
 1.53121E-06 -4.21400E-06 -1.23726E-06  2.01631E-06  0.00000E+00  0.00000E+00
       44
 2.74154E-07 -2.88095E-06 -1.95322E-06  2.84916E-06  0.00000E+00  0.00000E+00
       45
 1.89632E-07 -2.46993E-06 -4.77444E-07  1.20858E-06  0.00000E+00  0.00000E+00
       46
 1.55422E-06 -4.09379E-06 -1.20431E-06  2.51649E-06  0.00000E+00  0.00000E+00
       47
 4.37616E-07 -2.25349E-06 -1.90840E-06  3.98105E-06  0.00000E+00  0.00000E+00
       48
 4.18576E-07 -1.96548E-06 -5.25899E-07  1.17433E-06  0.00000E+00  0.00000E+00
       49
 1.51945E-06 -4.39280E-06 -1.01822E-06  2.58356E-06  0.00000E+00  0.00000E+00
       50
 1.94504E-07 -2.23810E-07 -1.84908E-06  5.38385E-06  0.00000E+00  0.00000E+00
       51
 3.80719E-07 -6.98605E-07 -4.37865E-07  5.75325E-07  0.00000E+00  0.00000E+00
      201
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.42928E-06  3.67272E-06
      203
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00 -3.98216E-06  1.96249E-06
   -1
   -1
   55
 INIT_20_50:           1/  2   20.303 HZ   0.00
MODE SHAPE SCALING: RESIDUES, FOR REF. NO.  0
ON NEXT LINE: ZETAP,ZETAP2,EMAC,MPC-W,MPC-U,MSR
   48.674    6.241    0.000   35.373    7.534    5.774
       23         2        12        13
        1         3         2        12         5         3
        2         6      1002         2
-7.10814E+01  1.27569E+02  3.12438E-01 -2.88287E-01 -1.45680E+01 -6.03492E+01
        1
 1.68725E-06  4.93854E-06 -4.64532E-06  2.45295E-06  0.00000E+00  0.00000E+00
        2
-1.02321E-07  9.81137E-06 -5.67560E-06  5.24888E-06  0.00000E+00  0.00000E+00
        3
-1.15826E-08  9.74699E-06 -3.56578E-06 -4.53548E-07  0.00000E+00  0.00000E+00
        4
 2.41506E-06  6.81966E-06 -6.52930E-06  3.30309E-06  0.00000E+00  0.00000E+00
        5
-1.14484E-07  1.35124E-05 -7.86990E-06  7.11402E-06  0.00000E+00  0.00000E+00
```

. . .

6.0 ANALYSIS PARAMETERS

This chapter describes all ERA analysis parameters in alphabetical order. Most parameters have default values. The default value is modified by redefining the parameter in Field 4 of the User Input file (FORTRAN NAMELIST format). The only exceptions are parameters MCH, MRH, MIC, MST, and MTIM that appear in Field 3 of the User Input file. All analysis parameters and their default values are printed at the beginning of every Tape50 file.

The names of all ERA analysis parameters adhere to the standard FORTRAN 77 convention of 6 letters or less. Those beginning with letters I through N are integer variables and all others are real variables.[168]

DATABW

DATABW is used to simplify the selection of N1, N2, and N3 for analysis of over-sampled data; i.e., data which has no spectral content above DATABW Hz. If DATABW is entered, N1, N2, and N3 are all set equal to (SF/2)/DATABW.

DATABW is an optional parameter. It is an acronym for "Data Bandwidth." There is no default value.

F1

F1 is an estimate of the frequency of the lowest-frequency mode. If F1 is entered, the number of cycles of data of this lowest-frequency mode is printed on Tape50. The number of cycles is computed as the product of F1 and WINDOW (the analysis window duration in seconds). If F1 is not entered, WINDOW is still printed on Tape50, from which users can estimate the number of cycles of the lowest-frequency mode themselves.

F1 is an optional parameter. It is an acronym for the "No. 1 Frequency." There is no default value.

---

[168] All analysis variables are read from Field 4 of the User Input file using a NAMELIST READ statement, which is a free-field read command. Thus, the usual decimal point requirements of FORTRAN for integer and real variables are unnecessary; conversion from integer to real format or vice versa is performed based on the declared variable type (i.e., INTEGER for all parameters beginning with the letters I though N and REAL for all others). For example, either "SF=20.0" or "SF=20" is acceptable syntax for specifying a sampling frequency of 20 Hz.

FMIN

FMIN is the minimum frequency in Hertz for bandlimited (zoom-transformed) data. Zoom-transformed data have frequency spectra that are translated upwards in frequency (from DC) by FMIN Hz. Such data are generated when a "zoom" analysis is performed during generation of frequency response functions. Zoomed data can also be obtained from time-domain free response data by inverse Fourier transformation followed by retaining only those spectral lines between FMIN and a desired upper frequency, followed by Fourier transformation back to the time domain. (That procedure is performed in ERA pre-processor ERAP20.)

FMIN is an optional parameter. It is an acronym for the "Minimum Data Frequency." The default value of FMIN is 0.0.

FR1FIR

Lower frequency in Hz of band- or low-pass finite impulse response (FIR) filter to apply to the Tape1 data before analysis. FIR filtering is activated by specifying both FR1FIR and FR2FIR, the lower and upper cutoff frequencies of the filter. The order of the FIR filter is given by parameter IORFIR (default value = 50). NTIM + IORFIR data points are necessary to use FIR filtering (i.e., MTIM must be equal to or greater than NTIM + IORFIR).

FR1FIR is an optional parameter. It is an acronym for the "1st Frequency of the FIR filter." There is no default value.

FR2FIR

Upper frequency in Hz of band- or low-pass finite impulse response (FIR) filter to apply to the Tape1 data before analysis. FIR filtering is activated by specifying both FR1FIR and FR2FIR, the lower and upper cutoff frequencies of the filter. The order of the FIR filter is given by parameter IORFIR (default value = 50). NTIM + IORFIR data points are necessary to use FIR filtering (i.e., MTIM must be equal to or greater than NTIM + IORFIR).

FR2FIR is an optional parameter. It is an acronym for the "2nd Frequency of the FIR filter." There is no default value.

ICAS85

ICAS85 specifies the Case Number to be used as the label for the first case written to Tape85. This parameter was introduced for situations where restricted queue time does not

permit a large looping job to be completed in its entirety. The job can be broken into smaller sub-jobs, and the resulting Tape85 files can then be combined (they are ASCII files) using the VMS APPEND command. ICAS85 is used to specify the starting case number for the second and subsequent sub-jobs (the first job will be numbered Case No. 1 by default).

ICAS85 is an optional parameter. It is an acronym for the starting "Case No. for Tape85." The default value of ICAS85 is 1.

IOMAC

IOMAC is an on/off switch (1=on, 0=off). If IOMAC = 1, input and output modal amplitude coherences are computed. **These calculations are obsolete,** superseded by the Extended Modal Amplitude Coherence (EMAC), which is both a better indicator and is much faster to compute. This parameter was introduced for the rare occasion when these older indicator values are also desired.

This is an obsolete option that is generally no longer used. IOMAC is an acronym for "Input/Output Modal Amplitude Coherence." The default value of IOMAC is 0.

IORDTU

IORDTU selects a particular order to use for the realization; i.e., a specified number of singular values to retain. The number of retained singular values equals the size (order) of the eigenvalue problem that is solved. **The number of retained singular values (IORDTU) equals twice the "assumed number of modes."** When this parameter is entered, all other singular value truncation options are deactivated. IORDTU can be incremented automatically for parametric studies by specifying LOOPOP = 1. See the description of LOOPOP for additional information on this feature.

IORDTU is an optional parameter. It is an acronym for "Order To Use." There is no default value.

IORFIR

The order of a band- or low-pass finite impulse response (FIR) filter to apply to the Tape1 data before analysis. FIR filtering is activated by specifying both FR1FIR and FR2FIR, the lower and upper cutoff frequencies of the filter. NTIM + IORFIR data points are necessary to use FIR filtering (i.e., MTIM must be equal to or greater than NTIM + IORFIR).

IORFIR is an optional parameter. It is an acronym for the "Order of the FIR filter." The default value of IORFIR is 50.

IPRABC

IPRABC is an on/off switch (1=on/0=off). If IPRABC = 1, the identified A, B, C, and D matrices are printed on Tape50.

IPRABC is an optional parameter. It is an acronym for "Print ABC." The default value of IPRABC is 0.

IPRDTA

IPRDTA is an on/off switch (1=on, 0=off). If IPRDTA = 1, all data records read from the Tape1 input files are printed on Tape50.[169]

IPRDTA is an optional parameter. It is an acronym for "Print Data." The default value of IPRDTA is 0.

IPREMC

IPREMC is an on/off switch (1=on, 0=off). If IPREMC = 1, the details of the EMAC calculation are printed on Tape55. If ITAPE(55) = 0 (i.e., Tape55 was not activated), it is activated by the software when IPREMC = 1 is specified.

IPREMC is an optional parameter. It is an acronym for "Print EMAC." The default value of IPREMC is 0.

IPREVS

IPREVS is an on/off switch (1=on, 0=off). If IPREVS = 1, all identified eigenvalues (both z- and s-plane formats) are printed on Tape50.

If ISTRIP > 1, s-plane mappings for z-plane angular strips from 1 to ISTRIP are printed.[170]

IPREVS is an optional parameter. It is an acronym for "Print Eigenvalues." The default value of IPREVS is 0.

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[169]Tape1 data records can also be printed using program ERAP0.

[170]Z-plane angular strip no. 1 extends from 0 to pi radians, strip no. 2 from pi to 2*pi radians, etc.

IPRHRS

IPRHRS is an on/off switch (1=on, 0=off). If IPRHRS = 1, the structure of the ERA data matrices (generalized Hankel matrices) is printed on Tape50. Additionally: if IPRHRS = 2, the data values themselves are printed rather than the structure of the matrices; if IPRHRS = 3, both the structure of the matrices and the data values are printed.

IPRHRS is an optional parameter. It is an acronym for "Print matrix HRS." (The Hankel matrix is often referred to as matrix HRS in the literature.) The default value of IPRHRS is 0.

IPRPAR

IPRPAR is an on/off switch (1=on, 0=off). If IPRPAR = 1, all primary variables with the program are printed on Tape50 in NAMELIST format. This option is used primarily by the author for debugging purposes.

IPRPAR is an optional parameter. It is an acronym for "Print Parameters." The default value of IPRPAR is 0.

IPRPDQ

IPRPDQ is an on/off switch (1=on, 0=off). If IPRPDQ = 1, the P, D, and Q matrices (SVD of the ERA data matrix, HRS0: P = left singular vectors, D = singular values, Q = right singular vectors) are printed on Tape50.

IPRPDQ is an optional parameter. It is an acronym for "Print matrices P, D, and Q." The default value of IPRPDQ is 09.

IPRREV

IPRREV is an on/off switch (1=on, 0=off). If IPRREV = 1, the time constants and initial amplitudes of all identified real eigenvalues (for all inputs and outputs) are printed on Tape50.

IPRREV is an optional parameter. It is an acronym for "Print Real Eigenvalues." The default value of IPRREV is 0.

IREFTU

IREFTU selects the reference (input) number to use for scaling residues written to Tape88 (if MSSCAL = 2). If IREFTU = 0, the maximum value among all references is used.

IREFTU is an optional parameter. It is an acronym for "Reference To Use." The default value of IREFTU is 0.

IRUNAV

IRUNAV is an on/off switch (1=on, 0=off). If IRUNAV = 1, a running average of instantaneous frequency and damping estimates, based on the input modal amplitude histories, are written to Tape80 in Universal File format.

This is a research option that is rarely used.

IRUNAV is an optional parameter. IRUNAV is an acronym for "Running Average option." The default value of IRUNAV is 0.

ISTRIP

ISTRIP designates the assumed z-plane angular strip for the identified eigenvalues. ISTRIP = 1 (the default) selects the primary strip from 0 to pi radians (measured counter-clockwise from the x axis). ISTRIP = 2 selects the second angular strip from pi to 2*pi, ISTRIP = 3 selects the third angular strip from 2*pi to 3*pi, etc. Values of ISTRIP greater than 1 can be used to obtain correct frequency and damping values for identified eigenvalues which have aliased ("folded") due to having frequencies greater than (SF/2)/N1.

ISTRIP is an optional parameter. It is an acronym for the "assumed z-plane angular Strip." The default value of ISTRIP is 1.

ITAPE()

ITAPE() is an array of on/off switches (1=on, 0=off). If ITAPE(N) = 1, output file N (i.e., "TapeN") is written. Presently, only 6 values of N are permissible: 50, 51, 55, 79, 85, and 88. (Tape80 is also still available, but is rarely used. Tape80 was used to store input modal amplitude time histories.)

However, rather than activating output files using parameter ITAPE(), the normal procedure is by using the ITAPES() variable; e.g., entering ITAPES=51,88 specifies that Tapes 51 and 88 are to be written. (This request could also be specified as ITAPE(51)=1,ITAPE(88)=1.)

See Chapter 4 for a description of all available output files.

By default, all output files are inactive except Tape50 and Tape85. Occasionally, it may be desirable to deactivate Tape50 (or Tape85), e.g., when performing a lengthy looping analysis. This can be accomplished by specifying ITAPE(50)=0 (or ITAPE(85)=0).

ITAPES()

ITAPES is an array variable used to simplify the activation of output files. Various output files are activated by entering ITAPES= followed by a list of the desired "Tape Nos." separated by commas. For example, entering ITAPES=51,88 specifies that Tapes 51 and 88 are to be written.

ITAPES() is an optional parameter. By default, all output files are inactive except Tapes 50 and 85. To deactivate these files, enter ITAPE(50)=0 and/or ITAPE(85)=0.

ITYDTA

ITYDTA specifies the type of impulse response functions (IRFs) used in the analysis, for scaling of mode shapes written to Tape88. ITYDTA is only applicable if MSSCAL = 0 (Modal-Plus scaling). This option provides complete compatibility with the unusual mode shape scaling convention used by Modal-Plus. Such scaling is necessary only if you wish to integrate ERA mode shapes with other modes (or portions of modes) derived using Modal-Plus procedures.

ITYDTA designations are as follows:

1 = Displacement/Force IRFs

2 = Velocity/Force IRFs

3 = Acceleration/Force IRFs

ITYDTA is an optional parameter. It is an acronym for the "Type of Data." The default value of ITYDTA is 3.

KEYDTA()

KEYDTA is an array variable used to select those data records (output numbers) to include in the generalized Hankel matrices below row NST (NST = the total number of response stations (outputs)).[171] The desired record numbers are specified in a NAMELIST input

[171]Currently, deletion of rows and columns of the ERA data matrices outside the main upper-left block of NST rows and NIC columns is only possible in the row (i.e., output) direction (using KEYDTA). No

statement such as KEYDTA=1,3,5,10 which selects records 1, 3, 5, and 10. The selections made with KEYDTA are used to activate the corresponding elements of array variable NSFLAG(). Alternatively, these selections can be made by setting the appropriate elements of NSFLAG() equal to 1 using a NSFLAG NAMELIST input statement. However, using KEYDTA= for this purpose is much simpler and is the recommended method.

KEYDTA is an optional parameter. It is an acronym for "Key Data." If neither KEYDTA nor NSFLAG appears in Field 4 of the User Input file, all NST data records are used to fill the lower portion (below row NST) of the data matrices.

LOOPOP

LOOPOP selects various looping options, as follows:

LOOPOP = 0: No looping. Perform single analysis only.

LOOPOP = -1: NSFRST is incremented from a value of PAR(1) to PAR(2) in steps of PAR(3). NSFRST is the first measurement number (data record) to include in the analysis from the Tape1 input files(s).

This option can be used to analyze each response measurement on the Tape1 file(s) separately (to investigate possible variations in frequency or damping results) by specifying PAR(1) = 1, PAR(2) = MST (the total no. of response measurements available), PAR(3) = 1, and NST = 1. This option can also be used to perform Monte Carlo analyses of simulated data, where sequential groups of response data on the Tape1 file(s) are corrupted by different sequences of random noise. Such data can be generated by program MIMO (Chapter 11) using parameter NCASES.

LOOPOP = 1: IORDTU is incremented from a value of PAR(1) to PAR(2) in steps of PAR(3). IORDTU is the "order to use"; i.e., the number of retained singular values.

This option is often used with PAR(3) = 2, in which case the "assumed number of modes" is incremented from a value of PAR(1)/2 to PAR(2)/2 in steps of PAR(3)/2.[172]

LOOPOP = 2: NSKIP is incremented from a value of PAR(1) to PAR(2) in steps of PAR(3). NSKIP is the number of data samples to skip at the beginning of every Tape1 data record.

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analogous capability exists to specify particular input numbers to include in the data matrices in columns greater than NIC.

[172]Modes of vibration correspond to complex-conjugate pairs of eigenvalues, so that IORDTU = N corresponds to N/2 assumed modes. IORDTU specifies the number of retained singular values which establishes the size (order) of the eigenvalue problem that is solved.

This option is used to perform sliding time-window analyses.

LOOPOP = 3: NCH is incremented from a value of PAR(1) to PAR(2) in steps of PAR(3). Also, NRH is set equal to NCH * PAR(4). NCH and NRH are the total number of columns and rows, respectively, in the generalized Hankel matrix.

This option permits the size of the generalized Hankel matrix to be increased (or decreased) in steps of NCH, while maintaining a constant ratio (PAR(4)) between NRH and NCH.

Note: When this option is used, MCH and MRH (the maximum values of NCH and NRH, respectively) must be set equal to the largest values that NCH and NRH will have throughout the entire analysis. These values are declared in Field 3 of the User Input file.

LOOPOP = 4: NRH is incremented from a value of PAR(1) to PAR(2) in steps of PAR(3).

This option permits the number of rows of the generalized Hankel matrix to be increased (or decreased) in steps of PAR(3), maintaining a constant number of columns (NCH).

Note: When this option is used, MRH (the maximum value of NRH) must be set equal to the largest value that NRH will have throughout the entire analysis. This value is declared in Field 3 of the User Input file.

LOOPOP = 5: NCH is incremented from a value of PAR(1) to PAR(2) in steps of PAR(3).

This option permits the number of columns of the generalized Hankel matrix to be increased (or decreased) in steps of PAR(3), maintaining a constant number of rows (NRH).

Note: When this option is used, MCH (the maximum value of NCH) must be set equal to the largest value that NCH will have throughout the entire analysis. This value is declared in Field 3 of the User Input file.

LOOPOP = 6: ISTRIP is incremented from a value of PAR(1) to PAR(2) in steps of PAR(3).

ISTRIP is the assumed z-plane angular strip for the identified eigenvalues. ISTRIP = 1 selects the primary strip from 0 to pi radians; ISTRIP = 2 selects the strip from pi to 2 * pi radians, etc.

LOOPOP = 7: N2LAST is incremented from a value of PAR(1) to PAR(2) in steps of PAR(3).

N2LAST is the number of data samples by which the last block row of the generalized Hankel matrix is shifted relative to the previous row. By default, N2LAST equals 10. All other block rows are normally shifted by an N2 value of 1. The final block row is shifted by a larger amount to permit the Extended Modal Amplitude Coherence (EMAC) to be more meaningful.

LOOPOP = 8: N3LAST is incremented from a value of PAR(1) to PAR(2) in steps of PAR(3).

N3LAST is the number of data samples by which the last block column of the generalized Hankel matrix is shifted relative to the previous column. By default, N3LAST equals 10. All other block columns are normally shifted by an N3 value of 1. The final block column is shifted by a larger amount to permit the Extended Modal Amplitude Coherence (EMAC) to be more meaningful.

LOOPOP = 9: Both N2LAST and N3LAST are incremented from a value of PAR(1) to PAR(2) in steps of PAR(3).

LOOPOP is an optional parameter. It is an acronym for "Looping Option." The default value of LOOPOP is 0.

MCH

MCH is the maximum number of columns in the generalized Hankel matrices. MCH is entered in Field 3 of the User Input file. This parameter establishes the dimension of several FORTRAN arrays within the program. Parameter NCH, the actual number of columns in the generalized Hankel matrices, is set equal to MCH by default (i.e., if no explicit value of NCH is entered in Field 4 of the User Input file). Parameter NCH can have any value less than or equal to MCH. Normally, except in looping analyses using LOOPOP = 3 or 5, the default value of NCH (equal to MCH) is used. The value of MCH is printed at the beginning of every Tape50 output file in parentheses to the right of the value of NCH.

MCH is specified in Field 3 of the User Input file by modifying the number xxx in the statement:

```
S/MCH=/MCH=xxx/
```

MCH is a mandatory parameter. It is an acronym for "Maximum number of Columns in the Hankel matrices." There is no default value.

MIC

MIC is the maximum number of initial conditions (inputs) used simultaneously in the analysis. MIC is entered in Field 3 of the User Input file. This parameter establishes the dimension of several FORTRAN arrays within the program. Parameter NIC, the actual number of initial conditions (inputs) used simultaneously in the analysis, is set equal to MIC by default (i.e., if no explicit value of NIC is entered in Field 4 of the User Input file). Parameter NIC can have any value less than or equal to MIC. Normally, the default value of NIC (equal to MIC) is used. The value of MIC is printed at the beginning of every Tape50 output file in parentheses to the right of the value of NIC.

MIC is specified in Field 3 of the User Input file by modifying the number xxx in the statement:

```
S/MIC=/MIC=xxx/
```

MIC is a mandatory parameter. It is an acronym for the "Maximum number of Initial Conditions." There is no default value.

MIDOPT

MIDOPT is specified in analyses where Coordinate-Code files are unavailable or unnecessary. By default (MIDOPT = 0), ERA will read the coordinate codes for Tape1 file T1fname.DAT from file TCfname.DAT. Coordinate-code files can be avoided by setting MIDOPT equal to one of the following values:

1: The response data read from the Tape1 file(s) are assumed to be consecutively numbered x-direction data.

2: The response data read from the Tape1 file(s) are assumed to be consecutive, interleaved x- and y-direction data.

3: The response data read from the Tape1 file(s) are assumed to be consecutive, interleaved x-, y-, and z-direction data.

MIDOPT is an optional parameter. It is acronym for "Measurement Identification Option." The default value of MIDOPT is 0.

MODELC

MODELC is used to generate a continuous-time state space model [A, B, C, D]. The data on the Tape1 input file(s) are assumed to be impulse response data. The first data point in

each Tape1 record is placed into the "D" matrix, and then the first data point is zeroed before the ERA analysis. The [A, B, C, D] matrices are written to Tape79 in MATRIXx ASCII format. The following options are available:

MODELC = 1: The analysis is stopped after the [A, B, C, D] matrices are written to Tape79 (users interested in [A, B, C, D] may have no interest in the identified modal parameters computed later in the procedure).

MODELC = 2: The analysis continues after [A, B, C, D] are written to Tape79, computing all modal parameters and accuracy indicators in the usual manner.

MODELC = 0 (the default): The [A, B, C, D] matrices are not stored on Tape79. The first data point in each Tape1 record is not zeroed.

MODELC is an optional parameter. It is an acronym for "Model Continuous." The default value of MODELC is 0. **Note**: If MODELC = 1 or 2, output Tape79 is automatically activated.

MODELD

MODELD is used to generate a discrete-time state space model [A, B, C, D]. The data on the Tape1 input file(s) are assumed to be pulse response data. First, the initial data point in each response record (t = 0) is extracted and placed into the D matrix. Then, the analysis continues using the remainder of the response data records. The [A, B, C, D] matrices are written to Tape79 in MATRIXx ASCII format. The following options are available:

MODELD = 1: The analysis is stopped after the [A, B, C, D] matrices are written to Tape79 (users interested in [A, B, C, D] may have no interest for the identified modal parameters computed later in the procedure).

MODELD = 2: The analysis continues after [A, B, C, D] are written to Tape79, computing all modal parameters and accuracy indicators in the usual manner.

MODELD = 0 (the default): all data is included in the analysis, beginning with the first data point; a traditional analysis is performed (assuming that the data are sampled impulse response functions), and the matrices [A, B, C, D] are not stored on Tape79. This is a traditional, continuous-time analysis.

MODELD is an optional parameter. It is an acronym for "Model Discrete." The default value of MODELD is 0. **Note**: If MODELD = 1 or 2, output Tape79 is automatically activated.

MRH

MRH is the maximum number of rows in the generalized Hankel matrices. MRH is entered in Field 3 of the User Input file. This parameter establishes the dimension of several FORTRAN arrays within the program. Parameter NRH, the actual number of rows in the generalized Hankel matrices, is set equal to MRH by default (i.e., if no explicit value of NRH is entered in Field 4 of the User Input file). Parameter NRH can have any value less than or equal to MRH. Normally, except in looping analyses using LOOPOP = 3 or 4, the default value of NRH (equal to MRH) is used. The value of MRH is printed at the beginning of every Tape50 output file in parentheses to the right of the value of NRH.

MRH is specified in Field 3 of the User Input file by modifying the number xxx in the statement:

```
S/MRH=/MRH=xxx/
```

MRH is a mandatory parameter. It is an acronym for the "Maximum number of Rows in the Hankel matrices." There is no default value.

MSRTOT

MSRTOT is an on/off switch (1=on, 0=off). If MSRTOT = 1, the total MSR (square root of the sum of squares) is printed on Tape50.

MSRTOT is an optional parameter. It is an acronym for "MSR TOTal" The default value of MSRTOT is 0.

MSSCAL

MSSCAL selects the type of mode shape scaling for data written to Tape88 in Universal File format. The following choices are available:

0: Standard Modal-Plus scaling.

1: Normalized to a maximum amplitude of 100 with the corresponding phase angles rotated to align best with +/- 90 degrees (see Ref. 8 for rotation procedure). This is the same scaling convention for the Normalized Mode Shape printed on Tape51.

-1: Normalized real vectors. Same normalization as MSSCAL = 1 followed by conversion to a real vector using the magnitude of each mode-shape component with the sign of the imaginary part.

2: Residues: With impulse response functions (IRFs), residues are the numerator terms in the partial fraction expansion of the corresponding frequency response function. The residue is computed as one-half of the identified initial modal amplitude, in physical units, with respect to the reference (input) number IREFTU. **NOTE**: Residues are applicable only for IRF data.

MSSCAL is an optional parameter. It is an acronym for "Mode Shape Scaling option." The default value of MSSCAL is 2.

MST

MST is the maximum number of response stations (outputs) used simultaneously in the analysis. MST is entered in Field 3 of the User Input file. This parameter establishes the dimension of several FORTRAN arrays within the program. Parameter NST, the actual number of response stations (outputs) used simultaneously in the analysis, is set equal to MST by default (i.e., if no explicit value of NST is entered in Field 4 of the User Input file). Parameter NST can have any value less than or equal to MST. Normally, the default value of NST (equal to MST) is used. The value of MST is printed at the beginning of every Tape50 output file in parentheses to the right of the value of NST.

MST is specified in Field 3 of the User Input file by modifying the number xxx in the statement:

```
S/MST=/MST=xxx/
```

MST is a mandatory parameter. It is an acronym for the "Maximum number of response Stations "There is no default value.

MTIM

MTIM is the maximum number of data samples available in each Tape1 data record.

Note: Set MTIM equal to the actual number of data samples available in each Tape1 data record.[173] Parameter NTIM, the actual number of data samples used in the analysis, is computed internally by the software. NTIM cannot be directly specified by the user.

MTIM is specified in Field 3 of the User Input file by modifying the number xxx in the statement:

```
S/MTIM=/MTIM=xxx/
```

[173]If you forget this value for your Tape1 data file(s), it can be determined using program ERAP0. Respond with "0" to the first question after entering the Tape1 file name.

MTIM is a mandatory parameter. It is an acronym for the "Maximum number of Time samples." There is no default value.

MXALL

MXALL is an on/off switch (1=on, 0=off). MXALL = 1 is a shortcut method for activating the following 4 parameters pertaining to the writing of various results to Tape79 in MATRIXx format: MXHANK, MXPDQT, MXMTM, and MXMOMC.

MXALL is an optional parameter. It is an acronym for "MATRIXx All." The default value of MXALL is 0.

MXDATA

MXDATA is an on/off switch (1=on, 0=off). If MXDATA = 1, all Tape1 data records are written to Tape79 in MATRIXx format. If FIR filtering is activated (w/ analysis parameters FR1FIR and FR2FIR), the data are written to Tape79 after filtering. Each data record is written as a separate MATRIXx variable. The variable name for Output NS and Input NI is t1_oNS_iNI.

MXDATA is an optional parameter. It is an acronym for writing Tape1 "Data." The default value of MXDATA is 0.

MXFLAG

MXFLAG is one of 4 singular-value truncation criteria (in addition to IORDTU, which is used to select a specific number of singular values to retain).[174] If IORDTU is not specified, singular value truncation occurs at the smallest order among the 4 criteria. MXFLAG is an on/off switch (1=on, 0=off). If MXFLAG = 1, this criterion selects the truncation point at the largest ratio of consecutive singular values, D(N)/D(N+1).

Note: Even when MXFLAG = 0, ratios of consecutive singular values are still examined. If the ratio exceeds 20, all other truncation criteria are bypassed (except IORDTU), and truncation occurs at the largest drop in singular values. A message is written to Tape50 to inform the user that this has occurred.

MXFLAG is an optional parameter. It is an acronym for "Maximum singular-value ratio Flag." The default value of MXFLAG is 0.

[174]The other criteria are RNKTOL, POFVAR, and MXORDR.

MXHANK

MXHANK is an on/off switch (1=on, 0=off). If MXHANK = 1, the generalized Hankel matrices are written on Tape79 in MATRIXx format.

MXHANK is an optional parameter. It is an acronym for writing "MATRIXx Hankel matrix." The default value of MXHANK is 0.

MXMOMC

MXMOMC is an on/off switch (1=on, 0=off). If MXHANK = 1, the Modal Controllability Matrix (MCM) and Modal Observability Matrix (MOM) are written to Tape79 in MATRIXx format. The Modal B Matrix (modal participation factors) are the first NIC columns of MCM. Similarly, the Modal C Matrix (mode shapes) are the first NST rows of MOM.

MXMOMC is an optional parameter. It is an acronym for writing "MATRIXx MOM and MCM matrices." The default value of MXHANK is 0.

MXMTM

MXMTM is an on/off switch (1=on, 0=off). If MXHANK = 1, the modal transformation matrix (MTM) is written to Tape79 in MATRIXx format. MTM contains the eigenvectors of the A matrix, used to transform B and C to modal participation factors and mode shapes, respectively

MXMTM is an optional parameter. It is an acronym for writing "MATRIXx MTM matrix." The default value of MXMTM is 0.

MXORDR

MXORDR is one of 4 singular-value truncation criteria (in addition to IORDTU, which can be used to select a particular number of retained singular values).[175] If IORDTU is not specified, singular value truncation occurs at the smallest order among the 4 criteria. MXORDR specifies the maximum number of singular values to be retained.

MXMTM is an optional parameter. It is an acronym for "Maximum Order." The default value of MXORDR is 0.75 * Min(NRH,NCH).

[175]The other criteria are RNKTOL, MXFLAG, and POFVAR.

MXPDQT

MXPDQT is an on/off switch (1=on, 0=off). If MXPDQT = 1, matrices P, D, and Q transpose (the singular value decomposition of HRS0) are written to Tape79 in MATRIXx format.

MXPDQT is an optional parameter. It is an acronym for writing "MATRIXx P, D, and Q Transpose matrices." The default value of MXPDQT is 0.

N1

N1 is the number of data samples between the 2 generalized Hankel matrices (HRS0 and HRS1). A value of N1 = 1 is normally used. Due to the cyclic nature of the transformation from z-plane eigenvalues to s-plane eigenvalues, all identified frequencies will alias ("fold") into the frequency interval from 0 to (SF/2)/N1 Hz. **Thus, if N1 > 1 is specified, the data should be prefiltered to eliminate all frequency components above (SF/2)/N1 Hz.** If N1 > 1 and optional parameter IPREVS is set equal to 1, all potential "unfolded" frequencies and damping factors for each eigenvalue are listed; i.e., the results for ISTRIP = 1 to N1 are printed. With this capability, it is possible to permit eigenvalues to alias and still recover the correct results.

It is permissible to enter negative values for parameter N1. In this case, the second Hankel matrix (HRS1) contains data at earlier times than the first Hankel matrix (HRS0). This approach permits the structural eigenvalues to be generally located outside of the z-plane unit circle while the "noise modes" will typically continue to be located inside the unit circle. Prior to printing the results on Tape50, the reciprocals of the z-plane eigenvalues are computed, so that proper frequency and damping results are obtained.

N1 is an optional parameter. The default value of N1 is 1.

N2

N2 is the number of data samples between the block rows of the generalized Hankel matrices. A value of N2 = 1 is normally used. Values of N2 greater than 1 cause a "stretching" of the data record which may result in some improvement of results for very low frequency modes. However, modes having frequencies at integer multiples of (SF/2)/N2 Hz will not be identified.[176] In this situation, the time shifts between block rows are exactly a multiple of one-half cycle of data (so that the "quadrature" portion of the waveform is undetected).

[176]If the corresponding mode shape is a real, or approximately real, vector (i.e., monophase).

N2 is an optional parameter. The default value of N2 is 1.

N2LAST

N2LAST is the number of data samples by which the last block row is shifted in the generalized Hankel matrices. Shifting of the last block row by an amount greater than the standard shift of N2 (normally equal to 1) is performed for the calculation of the output Extended Modal Amplitude Coherence (EMAC).

N2LAST is an optional parameter. The default value of N2LAST is 10.

N3

N3 is the number of data samples between the block columns of the generalized Hankel matrices. A value of N3 = 1 is normally used. Values of N3 greater than 1 cause a "stretching" of the data record which may result in some improvement of results for very low frequency modes. However, modes having frequencies at integer multiples of (SF/2)/N3 Hz will not be identified.[177] In this situation, the time shifts between block columns are exactly a multiple of one-half cycle of data (so that the "quadrature" portion of the waveform is undetected).

N3 is an optional parameter. The default value of N3 is 1.

N3LAST

N3LAST is the number of data samples by which the last block column is shifted in the generalized Hankel matrices. Shifting of the last block column by an amount greater than the standard shift of N3 (normally equal to 1) is performed for the calculation of the input Extended Modal Amplitude Coherence (EMAC).

N3LAST is an optional parameter. The default value of N3LAST is 10.

NCASES

NCASES is the total number of cases run in looping analyses. It is printed on Tape50 for information only.

NCASES is computed internally by the software; it is not specified by the user. It is an acronym for the "Number of Cases."

---

[177] If the corresponding modal participation vector is a real, or approximately real, vector (i.e., monophase).

NCH

NCH is the total number of columns in the generalized Hankel matrices. Although it is possible to directly specify a value of NCH in Field 4 of the User Input file, this is not the usual method. Instead, NCH is normally specified by entering a value for MCH in Field 3 of the User Input file. MCH is the maximum value that NCH can have in the analysis (MCH is a FORTRAN array dimension). By default, NCH equals MCH.

NCH can be incremented using LOOPOP = 3 or 5. In looping analyses, MCH must by no smaller than the smallest value that NCH will attain throughout the analysis.

NCH is an optional parameter. It is an acronym for the "Number of Columns in the Hankel matrices." The default value of NCH is MCH.

NGENTH

NGENTH is a research parameter that is not normally used. The advantages of using this capability have not yet been fully established. To use this capability, additional "generalized time histories" must be added to the end of each Tape1 data file. Such generalized time histories are, for example, a linear combination of actual data records. The number of records specified by NGEHTH is used as KEYDTA() records, and they are excluded from the components of identified mode shapes written to the various output files.

NGENTH is a research parameter that is seldom used. It is an acronym for the "Number of Generalized Time Histories." The default value of NGENTH is 0.

NIC

NIC is the number of initial conditions (number of response data sets to use simultaneously in the analysis). Although it is possible to directly specify a value of NIC in Field 4 of the User Input file, this is not the usual method. Instead, NIC is normally specified by entering a value for MIC in Field 3 of the User Input file. MIC is the maximum value that NIC can have in the analysis (MIC is a FORTRAN array dimension). By default, NIC equals MIC.

NIC is an optional parameter. It is an acronym for the "Number of Initial Conditions." The default value of NIC is MIC.

NOAD79

If NOAD79 =1 (and MODELD = 1 or 2, don't write [ad,bd,cd,dd] to Tape79. (Write [z_evalues,bd_modal,cd_modal,dd_modal].) This option was developed for applications when program ERAP10B is used to perform discrete-time simulations. ERAP10B uses

[z_evalues,bd_modal,cd_modal,dd_modal] and the Tape79 was becoming unacceptably large in looping analyses in [ad,bd,cd,dd] was also written to Tape79.

NOFATL()

NOFATL() is an array variable used to bypass fatal errors. Fatal error N generated by ERA is bypassed by including the following statement in Field 4 of the User Input file:

```
NOFATL(N) = 1
```

NOFATL() is an on/off switch (1=on, 0=off). The default value is 0.

If you override a fatal error, the error message still appears on Tape50. However, it is followed immediately by the following statement:

```
* NOFATL(N) = 1.  FATAL ERROR IS IGNORED *
```

for error number N.

Note: NOFATL() is a "hidden" analysis parameter that is not included in the list of parameters printed at the beginning of Tape50.

NRH

NRH is the total number of rows in the generalized Hankel matrices. Although it is possible to directly specify a value of NRH in Field 4 of the User Input file, this is not the usual method. Instead, NRH is normally specified by entering a value for MRH in Field 3 of the User Input file. MRH is the maximum value that NRH can have in the analysis (MRH is a FORTRAN array dimension). By default, NRH equals MRH.

NRH can be incremented using LOOPOP = 3 or 4. In looping analyses, MRH must by no smaller than the smallest value that NRH will attain throughout the analysis.

NRH is an optional parameter. It is an acronym for the "Number of Rows in the Hankel matrices." The default value of NRH is MRH.

NSFLAG()

NSFLAG is an array of 0's and 1's which indicates those output numbers which are included in the generalized Hankel matrices below row number NST (1 = include, 0 = do not include). Normally, the entries in this array are filled internally by the software based on values entered for parameter KEYDTA(). NSFLAG() is printed on the Tape50 listing in groups of 1-0 elements separated by spaces.

NSFLAG() is normally not specified directly by the user. The standard procedure for changing the elements of this array is by using KEYDTA(). If KEYDTA() is not entered in the User Input file, all elements of NSFLAG() are '1'.

NSFRST

NSFRST is the first data record used from the Tape1 input file(s). For example, if NSFRST = 6 and NST = 10, data records 6 through 15 are included in the analysis. There is currently no provision for specifying a noncontiguous group of Tape1 data records to use in the analysis. If this is desired, new Tape files must be created by the user which contain only the desired data records. Program ERAP5 can be used for this purpose.

NSFRST is an optional parameter. It is an acronym for the "First data record of NST to include in the analysis." The default value of NSFRST is 1.

NSKIP

NSKIP is the number of data samples skipped at the beginning of every data records read from the Tape1 input file(s). This parameter is often incremented to perform a sliding time window analysis using LOOPOP = 2. This procedure is used to investigate nonlinearity. If data samples are skipped at the beginning of impulse response function data (i.e., NSKIP > 0), the resulting realization will not model input-output behavior because of the time shift.

NSKIP is an optional parameter. It is an acronym for "Number of data samples to skip." The default value of NSKIP is 0.

NST

NST is the number of measurements (response stations). Although it is possible to directly specify a value of NST in Field 4 of the User Input file, this is not the usual method. Instead, NST is normally specified by entering a value for MST in Field 3 of the User Input file. MST is the maximum value that NST can have in the analysis (MST is a FORTRAN array dimension). By default, NST equals MST.

NST is an optional parameter. It is an acronym for the "Number of Response Stations." The default value of NST is MST.

NSTBOT

NSTBOT is the number of '1' entries in the NSFLAG() array, signifying the number of outputs included in the generalized Hankel matrices below row number NST. This value is printed on Tape50 for information only.

NSTBOT is computed internally by the software. It cannot be directly specified by the user.

NSTDTA

The value of NSTDTA is not normally of concern to the user. It is printed on Tape50 for information only. When a value of NGENTH is specified, NSTDTA = NST - NGENTH.

NSTDTA is computed internally by the software. It cannot be directly specified by the user.

NTIM

NTIM is the number of data samples (time points) used from each Tape1 data record. NTIM is not directly specified by the user. It is calculated by the software based on the values specified for other analysis parameters. However, users are always required to enter a value for MTIM in Field 3 of the User Input file. MTIM is the maximum number of time points that will be used in the analysis; i.e., MTIM is the maximum value that NTIM will attain. Rather than trying to calculate the exact maximum value that NTIM will have, simply set MTIM equal to the actual total number of data samples available in each Tape1 data record. If the computed NTIM exceeds this value, a fatal error will occur.

NTIM is calculated as follows:

```
NTIM = NSKPTU + IABS(N1) + (NTIMER-2)*N2 + (NTIMEC-2)*N3 + 1 +
       N2LAST + N3LAST + IORFIR

where NSKPTU = 0 if MODELD = 0
             = 1 else

and

NTIMER = 1 + ((NRH-NST-1)/NSTBOT + 1)
NTIMEC = ((NCH-1)/NIC) + 1
```

If time-domain FIR filtering is not activated (`FR1FIR` and `FR2FIR` do not appear in Field 4 of the User Input file), `IORFIR = 0`.

NTIM is computed internally by the software. It is not directly specified by the user. NTIM is an acronym for the "Number of Time Samples Used in the Analysis."

NUMRNK

NUMRNK is an on/off switch (1 = on, 0 = off). If NUMRNK = 1, singular value truncation will occur when the rank tolerance, RNKTOL, becomes equal to the default rank tolerance, RNKTL0. This truncation point corresponds with the numerical rank of the

generalized Hankel matrix, HRS0. It is the appropriate singular-value truncation point to choose when analyzing linear analytical data with no noise.

NUMRNK is an optional parameter. It should only be used when analyzing linear analytical data with no noise. It is an acronym for "Numerical Rank." The default value of NUMRNK is 0.

PAR()

PAR() is an array of parameters used in conjunction with LOOPOP to increment key analysis parameters. For each value of LOOPOP, PAR() contains the range of values over which to loop, the increment between loops, and any other information required by that particular LOOPOP selection.

Up to 10 parameters can be specified using PAR(), although no more than 4 are currently used by any LOOPOP selection.

The PAR() parameters are specified in the User Input file by placing their values after 'PAR=', separating the entries by commas. For example, to select LOOPOP=1, PAR(1)=10, PAR(2)=30, and PAR(3)=2, enter the following statement in Field 4 of the User Input file:

```
LOOPOP=1,PAR=10,30,2
```

Note that the elements of PAR() can be real values. With LOOPOP = 3, for example, PAR(4) specifies the ratio of NRH and NCH (NRH/NCH = PAR(4)). This ratio is not restricted to integer values.

POFVAR

POFVAR is one of 4 singular-value truncation criteria (in addition to IORDTU which specifies a particular number of singular values to retain).[178] If IORDTU is not specified, singular value truncation occurs at the smallest order among the 4 criteria. POFVAR is the cumulative percentage of data variance (CPV), computed as the running sum of the squares of the singular values. CPV is related to noise percentage and signal-to-noise ratio (SNR) as follows:

[178]The other criteria are RNKTOL, MXFLAG, and MXORDR.

% NOISE	SNR, dB	CPV, %
31.6	10	90.
10.0	20	99.
3.16	30	99.9
1.0	40	99.99
0.316	50	99.999
0.1	60	99.9999
0.0316	70	99.99999
0.01	80	99.999999

Table 6-1. Relationship of Percent Noise, SNR, and CPV

For example, if data contaminated by 1 percent noise are analyzed, the singular value plot will show a transition from the predominately signal region to the predominately noise region near a CPV value of 99.99 percent. Experience has shown that this transition between signal and noise regions of the singular value distribution plot often occurs near a CPV value of approximately 99.999 percent for impulse response functions derived from good quality frequency response functions. The transition is indicated by a general change in slope of the singular value plot from a relatively steep slope to a slope of approximately zero.

POFVAR is an optional parameter. It is an acronym for "Percent of Data Variance." The default value of POFVAR is 99.999.

RNKTL0

RNKTL0 is the default rank tolerance (i.e., the default value for parameter RNKTOL). RNKTL0 is computed internally by the software as

```
RNKTL0 = SQRT(NRH*NRH + NCH*NCH) * EPS
```

where NRH and NCH are the number of rows and columns, respectively, in the generalized Hankel matrices, and EPS is the computer precision. EPS is the smallest floating point number that when added to 1.0 equals a floating point number larger than 1.0. (It can be computed using program ERA$SOURCES:EPS.FOR.) If numerically simulated data with no noise are analyzed, singular value truncation should be made at a singular value ratio, D(N)/D(1), equal to RNKTL0. D(N) is the Nth singular value and D(1) is the first. This method of selecting the singular value truncation can be activated by specifying NUMRNK = 1.

RNKTL0 is printed on Tape50 for information only. It is computed internally by the software. RNKTL0 is not directly specified by the user.

RNKTOL

RNKTOL is one of 4 singular-value truncation criteria (in addition to IORDTU which specifies a particular number of singular values to retain).[179] If IORDTU is not specified, singular value truncation occurs at the smallest order among the 4 criteria. RNKTOL is the rank tolerance, computed as D(N)/D(1), where D(N) is the Nth singular value and D(1) is the first.

RNKTOL is an optional parameter. It is an acronym for "Rank Tolerance." The default value of RNKTOL is RNKTL0.

SF

SF is the data sampling frequency in samples per second. With "zoom-transformed" data, SF equals twice the data bandwidth, FMAX - FMIN.[180]

SF is a mandatory parameter. If must be specified in Field 4 of the User Input file in every analysis. SF is an acronym for "Sampling Frequency." There is no default value.

T55CMI

T55CMI specifies the minimum CMI for modes written to Tape55.

T55CMI is an optional parameter. It is an acronym for the "Tape55 CMI cutoff (minimum value)." The default value of T55CMI is 1.0 percent.

T88CMI

T88CMI specifies the minimum CMI for modes written to Tape88.

T88CMI is an optional parameter. It is an acronym for the "Tape88 CMI cutoff (minimum value)." The default value of T88CMI is 1.0 percent.

WINDOW

WINDOW appears on each Tape50 listing for information only. It specifies the total length of data used in the analysis in seconds. WINDOW is computed as follows:

[179]The other criteria are MXFLAG, POFVAR, and MXORDR.

[180]See discussion of Fig. 3-3 in Section 3.3.

```
WINDOW = (NTIM - 1 - NSKIP) / SF
```

The value of WINDOW is typically examined to ensure that a minimum of 2 - 3 cycles of data of the lowest-frequency mode are included in the analysis. User parameter F1 can optionally be entered to compute the number of cycles of the lowest-frequency mode. Parameter F1 is the estimated frequency of the lowest-frequency mode.

WINDOW is printed on Tape50 for information only. It is computed internally by the software. Users cannot directly specify WINDOW.

7.0 RUNNING ERA

ERA is a batch program.[181] All parameters required for each job are specified in a "User Input file" prior to execution. No additional inputs occur during program execution.

Execute ERA in one of the following three ways:

7.1 As a Batch Job

To execute ERA as a batch job, enter the following command:

```
ERA fname
```

where **fname** is the name of the User Input file. *The User Input file,* **fname**, *is assumed to reside in your current default directory.* The default file type for User Input files is **.ERA**. To differentiate ERA User Input files, it is highly recommended that file type **.ERA** be used. The jobname specified in Field 2 of the User Input file is normally used for filename **fname**, although this is not mandatory.

The following message appears on your computer screen when the ERA is submitted as a batch job:

```
Job ERA (queue SYS$BATCH, entry xx) started on SYS$BATCH
```

If file **fname** does not exist in your current default directory, you will receive the following error message shortly after entering the **ERA fname** command:

```
Job ERA (queue SYS$BATCH, entry xx) completed
  %COPY-E-OPENIN, error opening !AS as input
```

The **ERA** command submits the job to a batch queue named ERA_BATCH_QUEUE. By default, this logical name is assigned to queue SYS$BATCH. Your system manager can assign ERA_BATCH_QUEUE to a different queue, or he can establish symbols that allow you to switch queues easily.

When ERA executes as a batch job, your terminal is available for other purposes while the job runs. A message and beep are sent to your terminal when the job finishes. You can monitor the cumulative CPU time of the job during its execution using the VMS SHOW SYSTEM/BATCH command. A batch job continues to run if you log off the computer.

---

[181] Program execution is controlled by a VMS command procedure that executes with no user interaction. This command procedure can be submitted as a batch job, run interactively, or spawned as a subprocess.

Multiple ERA jobs can execute simultaneously if they have different Jobnames as defined in the Field 2 of the User Input file. Although each job creates several temporary files, unique names ensure that multiple jobs do not interact. The system deletes all temporary files at the end of a successful run. If the job aborts prematurely, however, these temporary files will remain in your directory. All temporary files have file type .TMP, and you must delete them yourself.

Multiple ERA jobs running simultaneously can access the same Tape1 and Coordinate-Code input files. Each job opens the file(s) using the READONLY qualifier on the FORTRAN OPEN statement so that multiple, simultaneous access is permitted.

It is impossible, however, to simultaneously run 2 ERA jobs having the same Jobname.

If you use the same Jobname as in a previous ERA run, the output files of the second job replace those of the first job.

With batch execution, you can examine ERA output files during execution using the VMS TYPE or EDIT/READ_ONLY commands.

7.2 As an Interactive Job

To execute ERA as an interactive job, enter the following command:

```
@ERA fname
```

where **fname** is the name of the User Input file. *The User Input File,* **fname**, *is assumed to reside in your current default directory.*

When ERA runs interactively, your terminal is locked and cannot be used for other purposes. You must abort ERA or open another window (if your terminal supports this feature) to perform other work. Running ERA interactively is generally the fastest method because VMS assigns high priority to interactive processes.

7.3 As a Spawned Job

To spawn ERA as a subprocess, enter the following command:

```
SPNERA fname
```

where **fname** is the name of the User Input file. *The User Input File,* **fname**, *is assumed to reside in your current default directory.*

This method permits your terminal to be used for other purposes while achieving the same priority as an interactive job. On many VAX systems, however, spawned jobs are not permitted (or are discouraged) by the system manager to limit the number of high-priority jobs.

Warning

Spawned jobs are *terminated* if you LOG OFF.

When ERA is executed as a spawned job, output files can be examined during execution using the VMS TYPE or EDIT/READ_ONLY commands.

8.0 PRE- AND POST-PROCESSORS

8.1 Index of Pre- and Post-Processors

An index of all ERA pre- and post-processors is available on-line by typing:

```
ERAPP
```

which is an acronym for "ERA Pre- and Post-Processors."

The following pre- and post-processors are currently available:

```
ERAP0  : LIST TAPE1 DATA.
ERAP0B : PRINT A DIRECTORY OF A TYPE 58 (FRF OR TIME HISTORY) UNIVERSAL FILE.

ERAP1  : BUILD  ERA TAPE1  FILE FROM SDRC TDAS OR MODAL-PLUS BINARY ADF FILE.
ERAP1B : BUILD MATLAB DATA FILE FROM SDRC TDAS OR MODAL-PLUS BINARY ADF FILE.

ERAP2  : BUILD ERA TAPE1 FILE FROM     FRF      DATA IN TYPE 58 .UNV FORMAT.
ERAP2B : BUILD ERA TAPE1 FILE FROM TIME HISTORY DATA IN TYPE 58 .UNV FORMAT.
ERAP2C : BUILD ERA TAPE1 FILE FROM DLR .RSP FILE HAVING   EQUALLY SPACED DATA.
ERAP2D : BUILD ERA TAPE1 FILE FROM DLR .RSP FILE HAVING UNEQUALLY SPACED DATA.

ERAP3  : BUILD      FRF     TYPE 58 UNIVERSAL FILE FROM ERA TAPE1 FILE.
ERAP3B : BUILD TIME-HISTORY TYPE 58 UNIVERSAL FILE FROM ERA TAPE1 FILE.
ERAP3C : BUILD  MODE SHAPE  TYPE 55 UNIVERSAL FILE FROM DLR .MOD FILE.

ERAP4  : SORT TAPE1 DATA RECORDS BY COORDINATE CODES (E.G., IN ASCENDING ORDER).
ERAP5  : EXTRACT VARIOUS PORTIONS OF VARIOUS RECORDS FROM A TAPE1 DATA FILE.
ERAP6  : CHANGE REF. LOCATION NO. AND/OR DIRECTION NO. IN A COORD. CODE FILE.

ERAP9  : BUILD "TAPE79" FILE FOR ERAP10B FROM NASTRAN MODE SHAPE .UNV FILE.

ERAP10 : TIME- OR FREQ-DOMAIN RECONSTRUCTION, USING DATA ON TAPE79.
ERAP10B: SIMULATION OF DISCRETE-TIME SYSTEMS (ARB. INPUTS), USING DATA ON TAPE79
ERAP10C: FREQ-DOMAIN RECONSTRUCTION OF FRFS, USING DATA ON TAPE88.
ERAP11 : PRINT OUT SCALED MODE SHAPES (RESIDUES OR UNITY-MODAL-MASS COEFFS.)
         USING B & C MATRICES ON TAPE79.

ERAP20 : DIGITALLY FILTER TAPE1 DATA BY FFT/ZEROING/IFFT.
ERAP21 : DIGITALLY FILTER TAPE1 DATA USING FIR LOW- OR BAND-PASS FILTER.
ERAP24 : INCREASE SF OF TAPE1 DATA BY ZERO-PADDING CORRESPONDING SPECTRA.
ERAP24B: ZERO-PAD TAPE1 TIME HISTORIES.

ERAP25 : CALCULATE MAC OR ORTHOGONALITY BETWEEN MODE SHAPES IN 2 UNV. FILES.

ERAP26 : VARIOUS UTILITY PROGRAMS FOR .UNV MODE SHAPE FILES.
ERAP27 : UTILITY PROGRAM TO PRINT OUT NO. OF DOFS IN A .LOC FILE (FOR ERAP25).
ERAP30 : GENERATE ANALYTICAL FRFS (THEN TAPE1 IRFS) USING NASTRAN .UNV FILE
ERAP40 : BUILD FRFS W/UNEQUALLY SPACED FREQ. LINES IN DLR .RSP FORMAT.
```

```
ERAP70 : CONVERT TIME HISTORIES ON NASTRAN PUNCH FILE TO TAPE1 FORMAT.

ERAP75A: CONVERT ERA TAPE1 FILE(S) TO MATRIXX ASCII FORMAT.
ERAP75B: CONVERT MATRIXX ASCII FILE TO ERA TAPE1 FORMAT.
ERAP76A: CONVERT ERA TAPE1 FILE(S) TO MATLAB BINARY .MAT FILE.
ERAP76B: CONVERT MATLAB BINARY .MAT FILE TO ERA TAPE1 FORMAT (MULTIPLE ARRAYS).
ERAP76C: CONVERT MATLAB  ASCII .MAT FILE TO ERA TAPE1 FORMAT ( ONLY 1 ARRAY !).

ERAP79 : CONVERT TAPE79 FILE (MATRIXX FORMAT) TO MATLAB .MAT FILE.
ERAP80 : EXTRACT A SPECIFIED CASE NO. FROM A TAPE79 FILE.

ERAP81 : CONVERT ERA TAPE1 FILE(S) TO TRANSPORTABLE, CODED FORMAT.
ERAP82 : CONVERT ERAP81-GENERATED FILE BACK TO ERA TAPE1 FORMAT.

ERAP85 : EXTRACT RESP. NOS. FROM TC FILE & BUILD LIST FOR P26_6.
ERAP85B: EXTRACT RESP. NOS. AND DIRS. FROM TC FILE & BUILD .LOC FILE FOR ERAP25.
ERAP88 : INTERLEAVE DATA ON 2 TAPE1 FILES (FOR OVERLAY PLOTTING W/ ERAG1, E.G.)
ERAP89 : UTILITY PROGRAM TO SUBTRACT CONSECUTIVE RECORDS IN A TAPE1 FILE.
ERAP89B: UTILITY PROGRAM TO SUM MULTIPLE TAPE1 RECORDS.
ERAP90 : CALC. RMS ERROR BETWEEN CONSECUTIVE TAPE1 RECS (OVER A TIME WINDOW).
ERAP91 : UTILITY PROGRAM TO APPEND PARTIAL TAPE1 RECORDS FROM 2 SEPARATE FILES.
ERAP92 : CALCULATE RMS OF TAPE1 DATA IN A TIME WINDOW & OVER >=1 RECS & FILES.
ERAP98 : UTILITY PROGRAM TO MULTIPLY TAPE1 DATA RECORDS BY A SPECIFIED CONSTANT
ERAP99 : UTILITY PROGRAM TO ADD NOISE TO TAPE1 DATA, FOR SIMULATION STUDIES.

ERAP125: TABULATE I.D.'ED MODES FOR SIMULATED EXPERIMENT SATISFYING 4 CRITERIA.

Graphics Programs (using DIGLIB):
---------------------------------

ERAG1  : PLOT TAPE1 DATA (TIME HISTORIES AND/OR SPECTRA).

ERAG2  : PLOT SPECTRA PEAKS USING SIMPLE N-POINT SLIDING WINDOW TO DETECT PEAKS
ERAG2B : PLOT TAPE1 SPECTRA AS WATERFALL PLOT.
ERAG2C : PLOT ENVELOPES OF TAPE1 HISTORIES (CALCULATED W/ HILBERT TRANSFORM).

ERAG3  : PLOT SINGULAR VALUES FROM TAPE85.
ERAG3B : PLOT EMAC OR CMI VALUES (ASCENDING ORDER) FROM TAPE85.
ERAG4  : PLOT AVG. POWER SPECTRUM AND/OR MODE INDICATOR FCT. USING TAPE1 DATA.
ERAG5  : PLOT MODE SHAPES (AMP. & PHASE VS. MEAS. NO.) FROM TAPE88 (.UNV FILES).
ERAG5B : PLOT MODE SHAPES (AMP. & PHASE VS. MEAS. NO.) FROM TAPE51.
ERAG6  : CALCULATE AND PLOT CROSS-CORRELATION COEFFS. OF TAPE1 DATA RECORDS.
ERAG7  : PLOT IDENTIFIED FREQS. AS DIAMONDS ON FREQ.-DOMAIN AMPLITUDE PLOTS.

ERAG10 : READ MODE SHAPE .UNV FILE & PLOT FREQUENCY VS. MODE NO.
ERAG15 : PLOT TAPE85 DATA VS. CASE NO.

ERAG25 : PLOT RESULTS FROM ERAP25, USING DARK SQUARES TO HIGHLIGHT HIGH VALUES.
ERAG26 : BAR PLOT OF MODE-BY-MODE INITIAL AMP. OF IRFS, USING NASTRAN .UNV FILE

ERAG50 : PLOT MODE SHAPES (WIREFRAME MODEL) FROM TAPE88 (.UNV FILES).

ERAG92 : PLOT MODAL STRENGTHS (RMS, PEAK) COMPUTED W/ ERAP10B & ERAP92 VS. FREQ.
```

8.2 Running Pre- and Post-Processors With GO

All ERA pre- and post-processors can be run interactively by simply typing their name. **Rather than running pre- and post-processors interactively, however, a much quicker method is available.** This method is referred to as the "GO Method," named for the simple command used to initiate it. The procedure is demonstrated below with program ERAG1 (see also Section 3.2).

Sample "GO input files" are stored in a global directory named ERA$GO. ERA$GO is a VMS logical name for directory ERA$DISK:[ERA.GO]. Copy the file named G1B_DEMO.COM into your current default directory by typing:

```
COPY ERA$GO:G1B_DEMO.COM []

(or COPY ERA$GO:G1B_DEMO.COM *)
```

Here is a listing of file G1B_DEMO.COM:

```
$! G1B_DEMO.COM
$!
$ RUN ERA$EXES:ERAG1
ERA$MMST_NAS:T1_MMST_NAS_SH2      TAPE1 FILENAME
74      FIRST RECORD TO PLOT
74      LAST RECORD TO PLOT
1       RECORD INCREMENT BETWEEN PLOTS
3       PLOT TYPE? 1=TIME, 2=FREQ, 3=BOTH
2       NO. OF PLOTS TO PLACE HORIZONTALLY ON PAGE
1       NO. OF PLOTS TO PLACE VERTICALLY ON PAGE
1       LINE STYLE?  1=SOLID, 2=SOLID & 3 DASHED (CYCLICALLY), 3=SOLID LINE...
1       LINEAR(0) OR LOG(1) SPECTRUM MAGNITUDE PLOT?
5       NO. OF DECADES TO USE ON FREQ. PLOT
0       VALUE FOR Y-AXIS MAX.  0=AUTOSCALE
0       HIGHLIGHT EACH DATA PT. ON SPECTRUM WITH A SYMBOL?  1=YES
1       INCLUDE COORDINATE CODES?  1=YES
160     SAMPLING FREQ., HZ
0       DATA FMIN
0       START TIME TO PLOT, SEC
32      FINAL TIME TO PLOT, SEC  [LARGE NO. TO PLOT COMPLETE HISTORY]
2       DELTA TIME (SEC.) FOR X-AXIS MINOR TIC MARKS.  0 = NONE
0        **   LINEAR(0) OR LOG(1) SCALE FOR TIME HISTORY Y-AXIS
0,0 IF **=0,MIN.,MAX. FOR TIME Y-AXIS. 0,0=AUTO. **=1,MAX.,NO. DECADES.0,-=AUTO
0       DELTA AMPL. FOR Y-AXIS MINOR TIC MARKS.  0 = NONE
0       HIGHLIGHT EACH DATA PT ON TIME HISTORY?  1=YES
0       STAIRSTEP TIME HISTORY PLOT? 1=YES
6       Y AXIS LABEL FOR TIME HISTORY. 1=T1DATA, 2=DISP IN IN., 3=DISP IN M, ...
        NO. OF POINTS TO FOURIER TRANSFORM (DEFAULT = ALL)
0       USE HANNING WINDOW?  1=YES
0       REMOVE DC VALUE?  1=YES
        FMIN TO PLOT (DEFAULT = DATA FMIN)
```

```
      FMAX TO PLOT (DEFAULT = SF/2 + DATA FMIN)
5     DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS
0.0   FREQ. FOR FIRST X-AXIS MINOR TIC MARK.  0.0 = ORIGIN OF PLOT
0     PLOT ABS(IMAG. PART) RATHER THAN MODULUS?  1=YES
0     SKIP SPECTRUM PHASE PLOT?  1=YES
1     INCLUDE X-AXIS GRID LINES ON FREQ. PLOT?  1=YES
1     ADD ADDITIONAL DOTTED VERTICAL LINES AT MINOR TICS?  1=YES
0.3   CHARACTER SIZE IN CM
1     FONT TYPE.  1=STICK, 2=BOLD LETTER QUALITY, 3=STD. LETTER QUALITY
0     PRINT OUT SPECTRUM TO FILE G1_SPECTRUM.OUT?  1=YES
1     USE DEFAULT OVERALL WINDOW SIZE?  1=YES
0     MODIFY DEFAULT AXIS NUMBERS?  1=YES
```

This file is a standard VMS command procedure (".COM file") that executes program ERAG1 (line 3), followed by the responses to 40 questions asked by ERAG1. **It would be very tedious indeed to enter all of these responses interactively.**[182] In addition to the responses, each line also contains a brief description of the corresponding question. Once you become familiar with a particular pre- or post-processor, these descriptions will be self-explanatory.

Although G1B_DEMO.COM is a standard VAX/VMS .COM file, do not execute it in the usual manner using the "@" command. Using "@" alone is insufficient for some ERA pre- and post-processors, particularly those involving graphics.[183] **Instead, run all GO input files by simply typing "GO" followed by the file name.** It is not necessary to type the ".COM" portion of the file name because this is the default file type for GO input files. **The GO input file is assumed to reside in your current default directory.** GO input files for program ERAxx are normally given names beginning with "xx_", although any name is permitted. For example, GO input files for ERAG1 written by the author have names beginning with "G1".

The "B" in the name of this example file (G1B_DEMO.COM) indicates that both time- and frequency-domain formats are requested. Other GO input files named G1T_DEMO.COM and G1F_DEMO.COM generate time- and frequency-domain plots alone. They are also available in directory ERA$GO.

Now, execute G1B_DEMO.COM by entering:

```
GO G1B_DEMO
```

The following information appears on your computer screen when G1B_DEMO is run:

```
ERAG1.  PLOT TAPE1 DATA USING DIGLIB
```

[182]Furthermore, if a pre- or post-processor is run interactively and you make a typing mistake, the program must be rerun from the beginning.

[183]Graphics programs begin with the letters "ERAG."

```
TAPE1 FILENAME ? [DEFAULT FILE TYPE = .DAT]
ERA$MMST_NAS:T1_MMST_NAS_SH2

FIRST RECORD NO. TO PLOT ?  (1)
         74

LAST RECORD NO. TO PLOT ?  (1)
         74

RECORD INCREMENT BETWEEN PLOTS ?  (1)
          1

PLOT TYPE DESIRED ?  (3)
 1 = TIME-DOMAIN ONLY
 2 = FREQ-DOMAIN ONLY
 3 = BOTH
          3

NO. OF PLOTS TO PLACE HORIZONTALLY ON THE PAGE ?  (2)
          2

NO. OF PLOTS TO PLACE VERTICALLY ON THE PAGE ?  (2)
          1

LINE STYLE ?  (1)
 1 = SOLID LINES
 2 = 4 ALTERNATING LINE TYPES: SOLID & 3 TYPES OF DASHED LINES
 3 = SOLID ON LINE #1 ONLY; THEN 3 TYPES OF ALTERNATING DASHED LINES
          1

LINEAR(0) OR LOG(1) AXIS FOR SPECTRUM MAGNITUDE ?  (1)
          1

NO. OF DECADES TO SHOW ON SPECTRUM MAGNITUDE PLOT ?  (4)
          5

VALUE TO USE FOR Y-AXIS MAX. ON SPECTRUM MAGNITUDE PLOT ? 0=AUTOSCALE  (0)
 0.0000000E+00

HIGHLIGHT EACH DATA PT. ON SPECTRUM WITH A SYMBOL ?  1=YES.  (0)
          0

INCLUDE COORDINATE CODES ON PLOT ?  1=YES.  (1)
          1

ENTER SF [SAMPLING FREQUENCY IN HERTZ] ?  (100.)
  160.0000

DATA FMIN ? [> 0 FOR ZOOMED DATA]  (0.)
 0.0000000E+00

   5120 TOTAL AVAILABLE TIME SAMPLES =   31.994 SECONDS
```

```
START TIME TO PLOT ?  (     0.000)
 0.0000000E+00

FINAL TIME TO PLOT ?  (    31.994)
  32.00000

REQUESTED FINAL TIME IS GREATER THAN THE AVAILABLE
DATA LENGTH.  FINAL TIME REDUCED TO    31.994

DELTA TIME (SEC.) FOR X-AXIS MINOR TIC MARKS ? 0 = NONE  (0.5)
  2.000000

PLOT TIME HISTORY USING LINEAR(0) OR LOG(1) Y-AXIS ? (0)
          0

MINIMUM & MAXIMUM VALUES FOR TIME HISTORY Y-AXIS ?  0,0 = AUTOSCALE
 0.0000000E+00  0.0000000E+00

DELTA AMPL. FOR Y-AXIS MINOR TIC MARKS ON TIME HISTORIES ? 0 = NONE  (1.0)
 0.0000000E+00

HIGHLIGHT EACH DATA PT. ON TIME HISTORIES WITH A SYMBOL ?  1=YES  (0)
          0

STAIRSTEP TIME HISTORY PLOT ?  1=YES  (0)
          0

SELECT Y AXIS LABEL FOR TIME HISTORY PLOT:  (1)
 0. USER SUPPLIED
 1. T1DATA
 2. DISPLACEMENT IN INCHES
 3. DISPLACEMENT IN METERS
 4. ACCELERATION IN G'S
 5. ACCELERATION IN M/SEC^2
 6. IMPULSE RESPONSE
 7. PULSE RESPONSE
 8. ACCEL. RESPONSE, CM/SEC^2
 9. FORCE, LBS
          6

ENTER NO. OF TIME SAMPLES TO FOURIER TRANSFORM ?  (  5120)
[ANY VALUE PERMITTED; SUBROUTINE SFT IS NOT RESTRICTED TO ONLY POWERS-OF-2]
       5120

USE HANNING WINDOW ? 1=YES.  (0)
          0

REMOVE DC VALUE ?  1=YES.  (0)
          0

FMIN TO PLOT ?  (  0.000)
 0.0000000E+00

FMAX TO PLOT ? (   80.000)
```

```
  80.00000

DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS ? 0=NONE  (1.0)
  5.000000

FREQ. OF FIRST X-AXIS MINOR TIC MARK ?  0.0 = ORIGIN OF PLOT. (0.0)
 0.0000000E+00

PLOT ABS(IMAG. PART) RATHER THAN MODULUS ?  1=YES.  (0)
          0

SKIP SPECTRUM PHASE PLOT ?  1=YES  (0)
          0

INCLUDE X-AXIS GRID LINES ON FREQ-DOMAIN PLOT
(AT EACH MAJOR TIC) ?  1=YES  (1)
          1

ALSO ADD ADDITIONAL DOTTED VERTICAL LINES AT MINOR TIC MARKS ?  1=YES.  (1)
          1

CHARACTER SIZE (HT.) FOR PLOT LABELS, IN CM ?  (0.3)
 0.3000000

FONT TYPE ?  (1)
 1 = STICK FONT
 2 = LETTER QUALITY - BOLD
 3 = LETTER QUALITY - STD.
          1

PRINT OUT SPECTRUM TO FILE G1_SPECTRUM.OUT ?  1=YES  (0)
          0

USE THE DEFAULT OVERALL WINDOW SIZE ? 1=YES  (1)
          1

MODIFY DEFAULT AXIS NUMBERS ?  1=YES  (0)
          0

GRAPHICS DEVICE NUMBER ?  (4)
  1 = TEK. 4010
  2 = TEK. 4014
  3 = TEK. 4025
  4 = TEK. 4107
  5 = TEK. 4115B
  6 = HP 2647/2648
  7 = DEC VT240
  8 = HPGL TALL
  9 = HPGL WIDE
 10 = POSTSCRIPT TALL
 11 = POSTSCRIPT WIDE
```

The ERAG1 program runs very rapidly with questions and responses flashing to your computer screen at a rate too fast to read. This is normal. To examine this information more closely, you must pause the display using the standard Ctrl S/Ctrl Q commands (Ctrl S to stop and Ctrl Q to continue) or using the F1 key on DEC terminals. Another method for examining the questions asked by any pre- or post-processor is to redirect the terminal text to a disk file. This is accomplished conveniently by appending an additional file name with the GO command, for example:

```
GO G1B_DEMO G1B.OUT
```

Everything that normally appears on your computer screen is now redirected to file G1B.OUT instead.

After all questions and responses scroll by, ERAG1 pauses at the question "GRAPHICS DEVICE NUMBER ?". You select the graphics device at this time.[184] **To simplify entering responses for any pre- or post-processor, a default value is shown in parentheses after most questions. The default value is selected by simply pressing RETURN.** For example, the default graphics device (4 = Tektronix 4107) is selected by pressing the return key when the list of choices is displayed. The default value is selected in GO input files by leaving one or more blank spaces at the beginning of a response line.

If you select graphics device No. 10 or 11 (PostScript), the following additional question is asked:

```
USE DEFAULT PLOT PARAMETERS ?  1=YES  (1)
```

Entering any number other than "1" permits changes to be made in the x,y magnification factors and line width of the plot. These characteristics (particularly the magnification factors) are often varied when hard copies of reduced size are generated for technical reports. Magnification factors less than 1.0 reduce the image size relative to full page size.

The appearance of graphics output varies slightly depending on the graphics device selected. **Fig. 8-1** shows the plot generated when G1B_DEMO is run using Graphics Device #11 (PostScript Wide).[185]

[184]Many other devices are available if you wish to add them to the list of choices. Instructions for doing so are provided in the DIGLIB User's Guide contained in file ERA$DIGLIB:DIGLIB.DOC. It is not necessary to read the DIGLIB User's Guide in order to use the ERA software.

[185]Your plot should <u>not</u> have a border. See Section 8.3 for explanation.

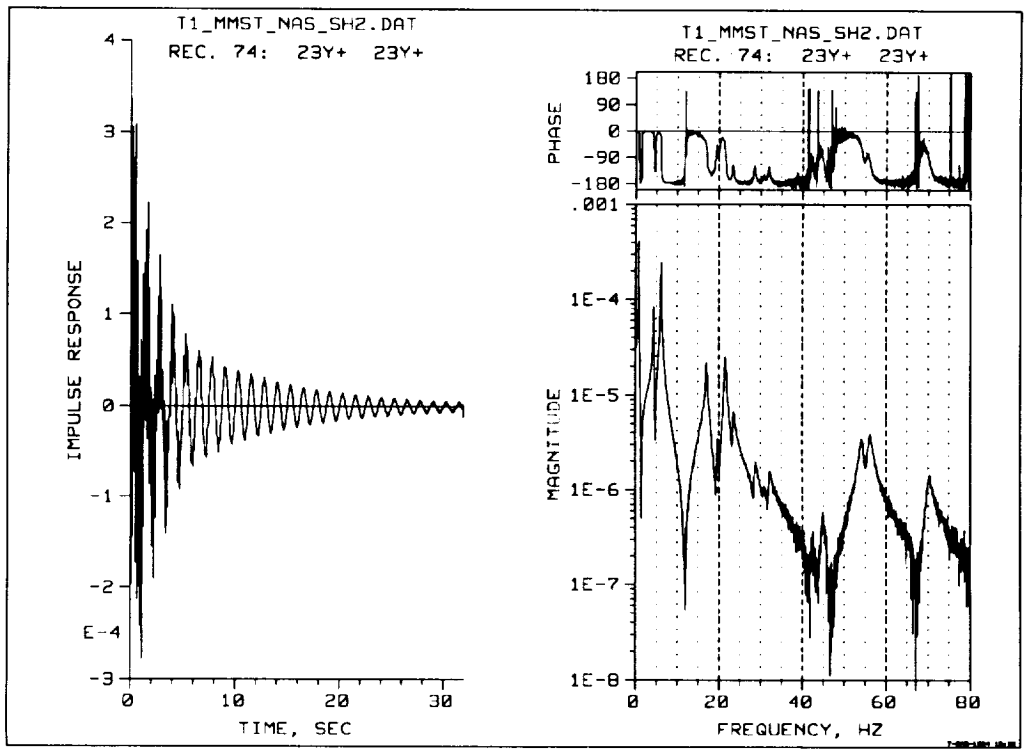

Fig. 8-1. Example Plot Generated by ERAG1

If multiple pages of graphics output are generated (e.g., by modifying file G1B_DEMO.COM to plot Records 74 and 75) and you display the output on a graphics terminal (Device Nos. 1 - 7), a pause occurs after each page. Press RETURN to continue. You may abort plotting at any time by entering Ctrl Y.

All other pre- and post-processors are run in the same manner. Simply edit a previous similar GO input file (directory ERA$GO contains many examples), and then type `GO filename`.

8.3 Hidden Options

In Fig. 8-1, a border appears around the edge of the plot. Your plot should not have included a border. Adding a border on the plot is a "hidden option" that is activated in the following way. Program ERAG1 looks for a file named G1_OPTIONS.DAT in your current default directory before reading responses from the GO input file. If found, this file is read using a FORTRAN NAMELIST read command. The variables included in the G1_OPTIONS.DAT file appear in a NAMELIST group named G1_OPTIONS (i.e., they

appear between a ' $G1_OPTIONS' card and a ' $END' card[186]). For example, to generate the plot shown in Fig. 8-1, file G1_OPTIONS.DAT contains the following 3 lines of code:

```
$G1_OPTIONS
IBORDR=1
$END
```

Setting variable IBORDR equal to 1 (1 = on, 0 = off) causes ERAG1 to draw the border around the plot. The default value of IBORDR is 0.

ERAG1 looks for file G1_OPTIONS.DAT in your current default directory. If found, the contents are read and echoed on your computer screen. You are then asked if it is okay to continue, as follows:

```
*** WARNING.  HIDDEN OPTIONS READ IN FROM FILE G1_OPTIONS:
$G1_OPTIONS
IBORDR  =           1,
NOTPLB  =           0,
MARKFD  =           0,
TFDNAM  = ' '
$END

O.K. TO CONTINUE ?  1=YES  (1)
```

Enter a "1" or press RETURN (selects the default) to proceed. All other responses terminate execution.

Hidden options are software features used only occasionally and/or only by certain users. A knowledgeable user can use these options while others (i.e., those not having an appropriate OPTIONS file in their default directory) are unaffected.

Hidden options for the other pre- and post-processors operate in a similar manner. Copies of some OPTIONS files are available in directory ERA$OPTIONS.

[186]An ampersand is equivalent to a dollar sign on the ' $G1_OPTIONS' and ' $END' cards. A blank character is necessary at the beginning of each line.

9.0 SISO AND MIMO TEST CASES

Programs SISO and MIMO construct ERA input files ("Tape1" files) of simulated, free-response data for single-input/single-output (SISO) and multiple-input/multiple-output (MIMO) systems, respectively. They execute interactively by simply typing their names, or (preferably) from a VMS command procedure as demonstrated in this chapter. This chapter discusses 2 test cases for each program. They are Test Cases SISO1, SISO2, MIMO1, and MIMO2. For control applications, test case MIMO2 shows how ERA generates a discrete-time state-space model using pulse response functions (ref. Section 2.4). The other test cases assume a continuous-time state-space model (ref. Section 2.3).

9.1 SISO

Program SISO generates noise-free, single-input/single-output data based on user-specified values of frequency, damping, amplitude, and phase for an arbitrary number of modes.[187] The program constructs one free-response time history consisting of the sum of exponentially decaying sinusoids and real exponential functions as follows:[188]

$$y(t) = \sum_{i=1}^{M} A_i e^{\sigma_i t} \cos(\omega_{di} t - \phi_i) + \sum_{j=1}^{N} A_j e^{\sigma_j t} \qquad (9\text{-}1)$$

where:
- $y(t)$ = Free-response time history
- M = No. of complex-conjugate pairs of eigenvalues (modes)
- N = No. of real eigenvalues
- A_i = Initial amplitude of mode i
- ϕ_i = Initial phase angle of mode i
- σ_i = Damping rate of mode $i = -\zeta_i \omega_{ni}$
- ζ_i = Damping factor of mode i (fraction of critical damping)
- ω_{ni} = Undamped natural frequency of mode i in rad/sec
- ω_{di} = Damped natural frequency of mode i in rad/sec = $\sqrt{1-\zeta_i^2}\,\omega_{ni}$

[187]There is no option with program SISO for adding noise to the simulated free-response data. Program SISO was developed to generate ideal free-response data (i.e., data with no noise or distortion). Program ERAP99 can be used to add noise to Tape1 data files if necessary. Or program MIMO can be run specifying only a single input and single output, ref. Section 9.2.

[188]Structural modes correspond to complex-conjugate pairs of eigenvalues. Real eigenvalues model distortion effects or actual system dynamics in control applications.

The objective of the ERA analysis is to identify: (1) the correct number of modes (M and N), and (2) the parameters characterizing each mode (frequency, damping, amplitude, and phase). **These results are identified entirely from the data itself, $y(t)$.**

9.1.1 Test Case SISO1: 3 Modes, Noise-Free Data

Test case SISO1 uses 3 modes with the following parameters:

Frequencies:	10, 15, and 30 Hz
Damping Factors:	1, 1, and 2 percent
Amplitudes:	1, 2, and 5.1234
Phase Angles:	90, -90, and 85.5 degrees

Program SISO generates a total of 1024 data points at a sampling frequency of 100 samples per second.

Run this test case by copying file RUN_SISO1.COM from directory ERA$TESTCASES to your working directory and executing it as a standard VMS command procedure as follows:

```
COPY ERA$TESTCASES:RUN_SISO1.COM []

(or COPY ERA$TESTCASES:RUN_SISO1.COM *)

@RUN_SISO1
```

Here is a listing of file RUN_SISO1.COM:

```
$! RUN_SISO1.COM
$!
$! CONSTRUCT TAPE1 FILE USING PROGRAM SISO (NIC=1,NST=1).
$! WRITE DATA TO FILE T1SISO1.DAT.
$!
$! NTIM = 1024 (NO. OF TIME POINTS TO GENERATE)
$!   SF = 100  (SAMPLING FREQUENCY IN SAMPLES PER SECOND)
$!
$! MODE NO.  FREQ.,HZ  ZETA,%   AMPLITUDE   PHASE,DEG.
$! --------  --------  ------   ---------   ----------
$!      1        10        1        1            90
$!      2        15        1        2           -90
$!      3        30        2        5.1234       85.5
$!
$ SISO
T1SISO1.DAT    TAPE1 FILE TO RECEIVE DATA
1024      NTIM
100       SF
10        FREQ. MODE 1 (ENTER 0.0 FOR REAL EIGENVALUE)
1         ZETAP MODE 1
1         AMPL. MODE 1
```

```
90        PHSD  MODE 1
Y         MORE MODES ?  Y OR N
15        FREQ. MODE 2
1         ZETAP MODE 2
2         AMPL. MODE 2
-90       PHSD  MODE 2
Y         MORE MODES ?  Y OR N
30        FREQ. MODE 3
2         ZETAP MODE 3
5.1234    AMPL. MODE 3
85.5      PHSD  MODE 3
N         MORE MODES ?  Y OR N
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$TESTCASES:SISO1.ERA []
$ @ERA SISO1
```

The following information appears on your computer screen when RUN_SISO1.COM is executed:

```
SISO.  A SIMPLE PROGRAM FOR BUILDING NOISE-FREE,
       SINGLE-INPUT/SINGLE-OUTPUT FREE RESPONSE DATA
       FOR ERA.

ENTER TAPE1 FILE NAME TO RECEIVE DATA. (MUST BEGIN WITH "T1")
[DEFAULT FILE TYPE = .DAT]
T1SISO1.DAT


NO. OF TIME SAMPLES TO GENERATE ? (1024)
       1024

DATA SAMPLING FREQUENCY IN SAMPLES PER SEC. ? (100.0)
  100.0000

ENTER THE PARAMETERS FOR MODE NO.  1:
FD (HZ) ?  ENTER 0.0 FOR A REAL EIGENVALUE. [<  50.0]  (10.0)
  10.00000
DAMPING FACTOR IN % ?  (1.0)
  1.000000
AMPLITUDE ?  (1.0)
  1.000000
PHASE IN DEG. ?  (90.0)
  90.00000

MODE NO.,FD,ZETAP,AMP0,PHSD = 1    10.000     1.000   1.0000E+00    90.0   <--

MORE MODES ?   Y OR N
Y
ENTER THE PARAMETERS FOR MODE NO.  2:
FD (HZ) ?  ENTER 0.0 FOR A REAL EIGENVALUE. [<  50.0]  (10.0)
  15.00000
```

```
DAMPING FACTOR IN % ?  (1.0)
  1.000000
AMPLITUDE ?  (1.0)
  2.000000
PHASE IN DEG. ?  (90.0)
 -90.00000

MODE NO.,FD,ZETAP,AMP0,PHSD = 2     15.000      1.000    2.0000E+00    -90.0    <--

MORE MODES ?   Y OR N
Y

ENTER THE PARAMETERS FOR MODE NO.  3:
FD (HZ) ?  ENTER 0.0 FOR A REAL EIGENVALUE. [<  50.0]  (10.0)
  30.00000
DAMPING FACTOR IN % ?  (1.0)
  2.000000
AMPLITUDE ?  (1.0)
  5.123400
PHASE IN DEG. ?  (90.0)
  85.50000

MODE NO.,FD,ZETAP,AMP0,PHSD = 3     30.000      2.000    5.1234E+00     85.5    <--

MORE MODES ?   Y OR N
N

DATA WRITTEN TO FILE T1SISO1.DAT


* * * RUNNING ERA * * *

ERA VERSION 931216

  10-MAR-1994 09:35:01


USER INPUT FILE NAME: SISO1.ERA
--------------------

ERA EXECUTION TIME = 1.56 SECS
```

Command procedure RUN_SISO1.COM constructs a Tape1 data file (ref. Section 4.1) named T1SISO1.DAT and then runs ERA interactively using User Input file SISO1.ERA (ref. Section 4.3). The parameters for constructing the data file appear in the lines following the program execution line, '$ SISO'. You can easily modify the number of time points generated (NTIM), the data sampling frequency (SF), and/or the frequency (in Hz), damping (in percent), initial amplitude, and initial phase angle (in degrees) of any mode. Additional modes can be included by changing the 'N' response to 'Y' and supplying the 4 parameters of each additional mode. Terminate the list with an 'N' response. Real

eigenvalues are specified by entering 0.0 for the frequency followed by the desired time constant in seconds ($\tau_j = |1/\sigma_j|$) and the initial amplitude.[189]

Test case SISO1 uses very simple data. **Fig. 9-1** shows the free-response time history and corresponding frequency spectrum. The spectrum is obtained from the time history by fast Fourier transformation (FFT). Each of the 3 modes is clearly defined and well separated in frequency from the others (uncoupled). This will not be the situation in Test Case SISO2 discussed in Section 9.1.2. Fig. 9-1 is generated with GO Input file G1B_SISO1.COM stored in directory ERA$GO. Section 8.2 gives instructions for running pre- and post-processors with GO.

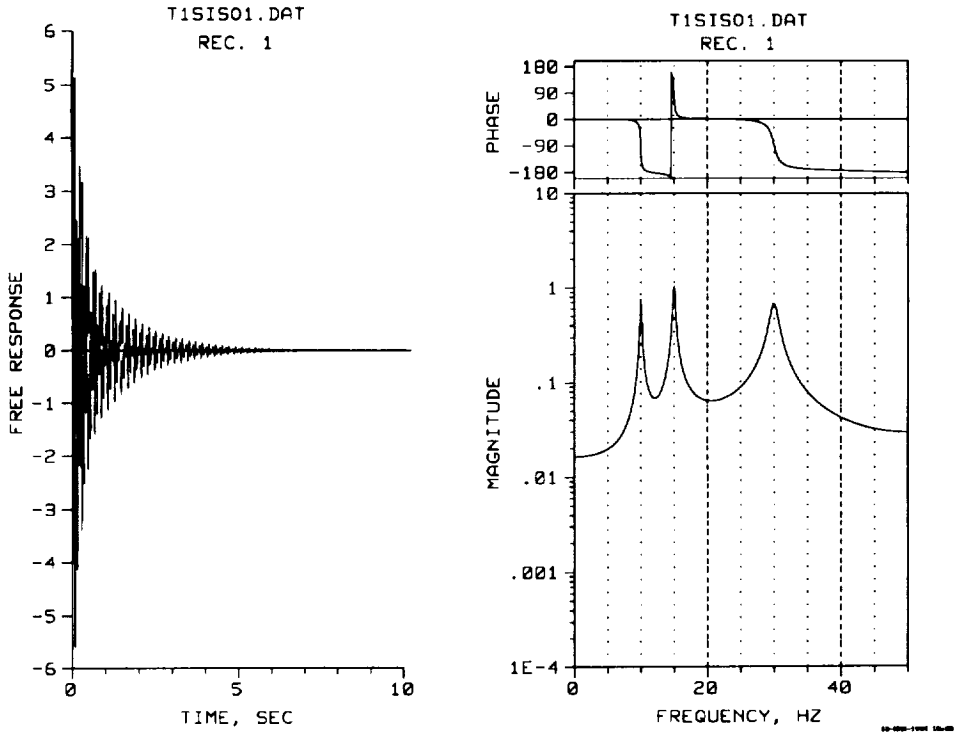

Fig. 9-1. Data and Spectrum of Test Case SISO1 (3 Modes) [G1B_SISO1.COM][190]

With SISO-generated data, ERA should determine the number of modes correctly (and automatically) and identify all parameters with high precision. Of course, repeated

[189]Example problem EX003 in Chapter 10 illustrates the identification of a real eigenvalue. See also the discussion in Section 12.7.

[190]The name in brackets in figure titles is the name of the GO Input file which generates the figure. Section 8.2 describes GO Input files.

eigenvalues (modes with identical frequency and damping) cannot be identified from single-input/single-output data (Ref. 3). Identification of a repeated eigenvalue of multiplicity *m* (with *m* eigenvectors) requires at least *m* linearly independent inputs (initial conditions) and at least *m* linearly independent outputs (response measurements).

Here is a listing of User Input file SISO1.ERA:[191]

```
$! SISO1.ERA
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=SISO1
$!
$ INPUT1:=SISO1
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=20/
S/MRH=/MRH=20/
S/MIC=/MIC=1/
S/MST=/MST=1/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=100,NUMRNK=1
 MIDOPT=1,MSTO50=1,MSPP50=0
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!            [ALWAYS USE EXACTLY 5 LINES]
$!
LINE 1 FOR USER-SUPPLIED JOB DESCRIPTION
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
SISO1: ERA TEST CASE 1 USING SISO
```

[191] Section 4.3 describes the contents of ERA User Input files. Chapter 7 explains how ERA is run.

The only technical information provided to ERA for this analysis is the data sampling frequency in samples per second (parameter SF in Field 4), the size of the generalized Hankel matrix specified by parameters MCH and MRH (Field 3), and optional parameter NUMRNK (Field 4). MCH is the total number of columns in the Hankel matrix, and MRH is the total number of rows (ref. Section 2.3.1, Eq. 2-17). Theoretically (with ideal data), MCH and MRH can both be as small as twice the number of modes comprising the data.[192] Parameter NUMRNK = 1 selects singular-value truncation at the numerical rank of the Hankel matrix.[193] **NUMRNK = 1 is a special option used only for analyzing noise-free simulated data.**

Three additional parameters, MIDOPT, MSTO50, and MSPP50, are specified in Field 4 of file SISO1.ERA. MIDOPT = 1 causes ERA to generate fictitious coordinate codes internally because no Coordinate-Code file is available (ref. Section 4.2). MSTO50 = 1 causes the identified mode shapes to be written to output file Tape50 (in the same format as to file Tape51 if it were activated). MSPP50 = 0 deactivates the mode shape "printer plot." That is, only the tabulated mode-shape results are written on Tape50. Chapter 6 provides additional information on all analysis parameters.

The ERA identification results are highlighted in bold type near the end of output file 50SISO1.LIS listed below. **All 4 parameters of each mode are identified <u>exactly</u>. Also, singular-value truncation occurred <u>automatically</u> at Order = 6, corresponding to 3 modes.** Note that Modal Phase Collinearity (MPC-W and MPC-U) and Phase Resonance Criterion (PRC) results are meaningless because only 1 response measurement is used in the analysis. RECIPROCITY is also meaningless because at least 2 inputs and 2 outputs are necessary for a valid calculation. Values of '-999' appear on Tape50 for these parameters to indicate meaningless results. Section 3.6 discusses the contents of the Tape50 output file.

The ERA analysis required 1.22 seconds of CPU time on the author's VaxStation 3100 computer.

---

[192]In practice, however, these dimensions should be greater than the theoretical minimum. MCH and MRH values 3 to 10 times greater than the number of modes are typically used successfully. Example problem EX014 (Section 10.14) reruns Test Case SISO1 with minimum Hankel matrix dimensions (6 x 6). All 3 modes are accurately identified. Appendix I gives guidelines for selecting the Hankel matrix size in practice.

[193]Numerical rank is the rank of the matrix based on the numerical resolution of the SVD computation. It corresponds to a rank tolerance of RNKTL0 = SQRT(NRH*NRH + NCH*NCH) * EPS, where EPS is the machine precision (Ref. 20). Rank tolerance is the ratio of singular value n divided by the largest singular value, $D(n)/D(1)$.

File 50SISO1.LIS

```
* * * ERA -- VERSION 931216 * * *


LINE 1 FOR USER-SUPPLIED JOB DESCRIPTION
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
SISO1: ERA TEST CASE 1 USING SISO


TAPE1 FILE NAMES:
----------------
   1. []T1SISO1.DAT

ANALYSIS PARAMETERS:                                                                                                  DEFAULT
-------------------                                                                                                    VALUE
                 (MAX)                                                                                                 -------
 NCH .......  20 (   20)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                              MCH
 NRH .......  20 (   20)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                              MRH
 NIC .......   1 (    1)  - NO. OF INITIAL CONDITIONS (INPUTS)                                                          MIC
 NST .......   1 (    1)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                                  MST
*NTIM ......  58 ( 1024)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)              -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                             -
*WINDOW ....     0.570    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                                  -
 FMIN ......     0.000    - FMIN OF DATA (FOR "ZOOMED" DATA)                                                        0.0

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                    -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                    -
 IORFIR ....  50          - ORDER OF BANDPASS FIR FILTER                                                             50

 NSFRST ....   1          - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                            1
 NSFLAG() ..               - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]    ALL 1
         1
*NSTBOT ....   1          - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                     NST

 NGENTH ....   0          - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)  0
*NSTDTA ....   1          - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                              -

 N1 ........   1          - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                           1
 N2 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                               1
 N3 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                               1
 N2LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                        10
 N3LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                        10

 NSKIP .....   0          - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                    0
 ISTRIP ....   1          - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                    1
 ICAS85 ....   1          - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                             1
 DATABW ....  -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1  -

 MODELC ....   0          - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 MODELD ....   0          - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 NOAD79 ....   0          - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)     0

*RNKTL0 ....  1.69E-06    - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)              SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....-999           - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")                      -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-----------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  1.69E-06     - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                              RNKTL0
 2. MXFLAG .  0            - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                 0
 3. POFVAR . 101.0000      - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                          99.999
 4. MXORDR .  20           - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                      0.75 * MIN(NRH,NCH)

 NUMRNK ....   1           -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BY-PASSING CRITERIA 1-4 ABOVE  0

 MIDOPT ....   1           - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]              0

 ITAPE(50) .   1           - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                           1
 ITAPE(51) .   0           - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                               0
 ITAPE(55) .   0           - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                   0
 ITAPE(79) .   0           - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                         0
  MXALL ....   0           -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                           0
  MXHANK ...   0           -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                        0
  MXPDQT ...   0           -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                            0
  MXMTM ....   0           -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT          0
  MXMOMC ...   0           -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                         0
  MXDATA ...   0           -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                          0
   MXDNTM ..-999           -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79    MTIM
   MXDNSF ..   1           -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                        1
   MXDNSL ..   1           -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                      NST
   MXDNIF ..   1           -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                        1
   MXDNIL ..   1           -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                      NIC
 ITAPE(80) .   0           - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...   0           - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80         0
```

```
 ITAPE(85) .    1          - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85          1
 ITAPE(88) .    0          - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                          0
 ITYDTA ....    3          - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                        3
 MSSCAL ....    2          - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES       2
 IREFTU ....    0          - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)   0
 T55CMI ....      1.0      - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                    1.0
 T88CMI ....      1.0      - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                    1.0

 MSTO50 ....    1          - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                     0
 MSPP50 ....    0          - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)               1

 LOOPOP ....    0          - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                  0
  PAR(1) ... -999.00        -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                     -
  PAR(2) ... -999.00        -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                     -
  PAR(3) ... -999.00        -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                     -
  PAR(4) ... -999.00        -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                     -
  PAR(5) ... -999.00        -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                     -
*NCASES ....    1          - NO. OF CONSECUTIVE CASES TO RUN                                                            1

 IPREMC ....    0          - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                     0
 IPRHRS ....    0          - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH  0
 IPRPDQ ....    0          - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                              0
 IPRABC ....    0          - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                          0
 IPREVS ....    0          - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                              0
 IPRDTA ....    0          - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                         0
 IPRPAR ....    0          - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                         0
 MSRTOT ....    0          - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                              0

 IOMAC .....    0          - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1              0
 ---------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ---------------------------------------------------------------


SISO1: ERA TEST CASE 1 USING SISO

CASE NO.   1:
------------

D(1) =   2.81367E+01

                                                                                                                CUMULATIVE
SINGULAR VALUES, D():                                                                  D(N)/D(1)  D(N)/D(N+1)  % OF VARIANCE   N

  1 ********************************************************************************************************  1.00E+00      1.047    35.90884   1
  2 *******************************************************************************************************  9.55E-01      1.498    68.64647   2
  3 ******************************************************************************************************   6.37E-01      1.203    83.22763   3
  4 *****************************************************************************************************    5.30E-01      1.655    93.30160   4
  5 ***************************************************************************************                  3.20E-01      1.103    96.97828   5
  6 **********************************************************************************                     2.90E-01* 3.046E+05   100.00000   6

  7 XXXXXXXXXXXXXXXXXXXXXXX                                                              9.52E-07      1.130   100.00000   7
  8 ++++++++++++++++++++++                                                                8.42E-07      1.297   100.00000   8
  9 ++++++++++++++++++++++                                                                6.50E-07      1.107   100.00000   9
 10 ++++++++++++++++++++                                                                  5.87E-07      1.400   100.00000  10
 11 ++++++++++++++++++                                                                    4.19E-07      1.129   100.00000  11
 12 ++++++++++++++++++                                                                    3.71E-07      1.101   100.00000  12
 13 ++++++++++++++++                                                                      3.37E-07      1.032   100.00000  13
 14 ++++++++++++++++                                                                      3.27E-07      1.038   100.00000  14
 15 ++++++++++++++++                                                                      3.15E-07      1.017   100.00000  15
 16 ++++++++++++++++                                                                      3.10E-07      1.270   100.00000  16
 17 ++++++++++++++                                                                        2.44E-07      1.153   100.00000  17
 18 ++++++++++++++                                                                        2.11E-07              100.00000  18
 19 +                                                                                     0.00E+00              100.00000  19
 20 +                                                                                     0.00E+00              100.00000  20

                                    NUMERICAL RANK =   6
                                    --------------------

                        *  SINGULAR VALUE TRUNCATION OCCURRED AT ORDER =   6  *


INPUT (REFERENCE) COORDINATE CODES:
----------------------------------
  IC NO.     COORDINATE CODE       MEAS. NO.
    1             1X+                1


* NOTE: FMIN =     0.0000, SF =   100.0000, N1 =  1, ISTRIP =  1.

  THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN       0.0000 &     50.0000 HZ


IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):
-----------------------------------------------------------------
```

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	OUTPUT (1)		MPC-W	MPC-U	PRC		ARATIO	RECIP-PROCITY	MSR,%
1	2	15.000**	1.000	(1.000)	:	100.00**	100.00	1	1	:	-999.00	-999.00	-999	:	0.590	:-999.0	50.4
2	1	10.000**	1.000	(1.000)	:	100.00**	100.00	1	1	:	-999.00	-999.00	-999	:	0.703	:-999.0	26.7
3	3	30.000**	2.000	(2.000)	:	100.00**	100.00	1	1	:	-999.00	-999.00	-999	:	0.121	:-999.0	81.8

IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	OUTPUT (1)		MPC-W	MPC-U	PRC		ARATIO	RECIP-PROCITY	MSR,%
1	3	30.000**	2.000	(2.000)	:	100.00**	100.00	1	1	:	-999.00	-999.00	-999	:	0.121	:-999.0	81.8
2	2	15.000**	1.000	(1.000)	:	100.00**	100.00	1	1	:	-999.00	-999.00	-999	:	0.590	:-999.0	50.4
3	1	10.000**	1.000	(1.000)	:	100.00**	100.00	1	1	:	-999.00	-999.00	-999	:	0.703	:-999.0	26.7

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	OUTPUT (1)		MPC-W	MPC-U	PRC		ARATIO	RECIP-PROCITY	MSR,%
1	1	10.000**	1.000	(1.000)	:	100.00**	100.00	1	1	:	-999.00	-999.00	-999	:	0.703	:-999.0	26.7
2	2	15.000**	1.000	(1.000)	:	100.00**	100.00	1	1	:	-999.00	-999.00	-999	:	0.590	:-999.0	50.4
3	3	30.000**	2.000	(2.000)	:	100.00**	100.00	1	1	:	-999.00	-999.00	-999	:	0.121	:-999.0	81.8

EIGENVALUE NO. 1 FREQUENCY = 10.000 HZ

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE		INITIAL PHYSICAL AMPLITUDES IC # 1	1X+
1	**10.000****	**1.000**	1X+	1	100.00	90.0	**1.0000E+00**	**90.0**

NORMALIZED MODAL PARTICIPATION FACTOR(S): 100.00 0.0

EIGENVALUE NO. 2 FREQUENCY = 15.000 HZ

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE		INITIAL PHYSICAL AMPLITUDES IC # 1	1X+
2	**15.000****	**1.000**	1X+	1	100.00	90.0	**2.0000E+00**	**-90.0**

NORMALIZED MODAL PARTICIPATION FACTOR(S): 100.00 0.0

EIGENVALUE NO. 3 FREQUENCY = 30.000 HZ

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE		INITIAL PHYSICAL AMPLITUDES IC # 1	1X+
3	**30.000****	**2.000**	1X+	1	100.00	90.0	**5.1234E+00**	**85.5**

NORMALIZED MODAL PARTICIPATION FACTOR(S): 100.00 -4.5

VAX EXECUTION STATISTICS:

```
COMPUTER NODENAME AND TYPE:  SDBHR,  VAXstation 3100-M76/GPX

ELAPSED:     0 00:00:05.69  CPU: 0:00:01.22  BUFIO: 53  DIRIO: 115  FAULTS: 1069

START DATE/TIME:  10-MAR-1994 10:24
  END DATE/TIME:  10-MAR-1994 10:24
```

9.1.2 Test Case SISO2: 30 Modes, Noise-Free Data

Test Case SISO2 is similar to Test Case SISO1 except it uses 20 modes instead of only 3. Also, a much wider range of modal amplitudes (0.001 - 5.1234 for SISO2 vs. 1.0 - 5.1234 for SISO1) occurs. Run this test case by copying file RUN_SISO2.COM into your working directory and executing it as a standard VMS command procedure as follows:

```
COPY ERA$TESTCASES:RUN_SISO2.COM []

@RUN_SISO2
```

Here are the parameters of Test Case SISO2:

MODE NO.	FREQ.,HZ	ZETA,%	AMPLITUDE	PHS,DEG.
1	10	1	1	90
2	15	1	2	-90
3	20.2	0.2	1	20
4	20.6	0.6	2	-60
5	21.0	1.0	3	100
6	21.4	1.4	4	-140
7	21.8	1.8	5	180
8	25.0	0.5	0.1	0
9	25.5	0.5	0.05	20
10	26.0	0.5	0.02	40
11	26.5	0.5	0.01	60
12	27.0	0.5	0.005	80
13	30	2	5.1234	90
14	31	1.031	1.031	31
15	32	1.032	1.032	32
16	33	1.033	1.033	33
17	34	1.034	1.034	34
18	35	1.035	1.035	35
19	40	1	.001	40
20	45	1	.001	45

```
NTIM = 1024
SF = 100
```

Fig. 9-2 shows the free-response time history and corresponding frequency spectrum of test case SISO2. Approximately half of the 20 modes are indiscernible in the spectrum because of their small amplitude and/or proximity to other modes. **Accurate identification of the frequency, damping, amplitude, and phase of all 20 modes is indeed a non-trivial undertaking.**

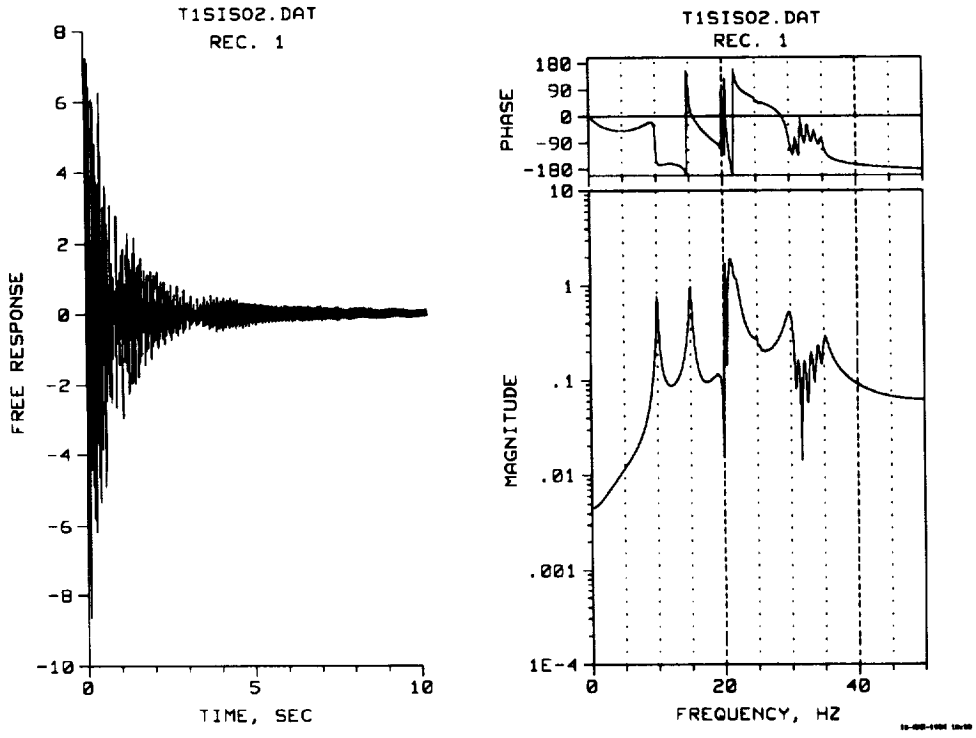

Fig. 9-2. Data and Spectrum of Test Case SISO2 (20 Modes) [G1B_SISO2.COM]

The following User Input file, SISO2.ERA, performs the ERA analysis:

```
$! SISO2.ERA
$!
$!    ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!        [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=SISO2
$!
$ INPUT1:=SISO2
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
```

```
$!                          MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=120/
S/MRH=/MRH=120/
S/MIC=/MIC=1/
S/MST=/MST=1/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                        OF AVAILABLE PARAMETERS]
$!
 SF=100,NUMRNK=1
 MIDOPT=1,MSTO50=1,MSPP50=0
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!              [ALWAYS USE EXACTLY 5 LINES]
$!
LINE 1 FOR USER-SUPPLIED JOB DESCRIPTION
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
SISO2: ERA CASE 2 USING SISO
```

File SISO2.ERA is identical to file SISO1.ERA used in Section 9.1.1 except that the Hankel matrix size (parameters MCH and MRH) increases from 20 x 20 to 120 x 120 because of the larger number of modes (20 modes rather than 3).

The identification results for Test Case SISO2 are highlighted in bold type at the end of output file 50SISO2.LIS listed below.[194] **All 4 parameters of each mode are well identified.** Modes having the smallest amplitudes (modes 10-12 and 19-20) display the largest parameter errors. Corresponding CMI values for these modes are also the lowest. Singular-value truncation occurred automatically at Order = 40, corresponding to 20 modes. The ERA analysis required approximately 22 sec of CPU time on the author's VaxStation 3100 computer.

[194]This is a partial listing of file 50SISO2.LIS.

File 50SISO2.LIS (partial)

```
* * * ERA -- VERSION 931216 * * *


LINE 1 FOR USER-SUPPLIED JOB DESCRIPTION
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
SISO2: ERA CASE 2 USING SISO


TAPE1 FILE NAMES:
----------------
   1. []T1SISO2.DAT

ANALYSIS PARAMETERS:                                                                                                  DEFAULT
-------------------                                                                                                    VALUE
                (MAX)                                                                                                  -------
 NCH ....... 120 (  120)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                              MCH
 NRH ....... 120 (  120)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                              MRH
 NIC .......   1 (    1)  - NO. OF INITIAL CONDITIONS (INPUTS)                                                         MIC
 NST .......   1 (    1)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                                 MST
*NTIM ...... 258 ( 1024)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)              -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                              -
*WINDOW ....     2.570    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                                   -
 FMIN ......     0.000    - FMIN OF DATA (FOR "ZOOMED" DATA)                                                         0.0

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                     -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                     -
 IORFIR ....  50          - ORDER OF BANDPASS FIR FILTER                                                             50

 NSFRST ....   1          - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                            1
 NSFLAG() ..               - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]    ALL 1
          1
*NSTBOT ....   1          - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                     NST

 NGENTH ....   0          - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)  0
*NSTDTA ....   1          - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                               -

 N1 ........   1          - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                            1
 N2 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                                1
 N3 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                                1
 N2LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                         10
 N3LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                         10

 NSKIP .....   0          - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                     0
 ISTRIP ....   1          - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                     1
 ICAS85 ....   1          - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                              1
 DATABW ....  -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1  -

 MODELC ....   0          - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 MODELD ....   0          - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 NOAD79 ....   0          - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)     0

*RNKTL0 ....  1.01E-05    - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)                  SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....-999           - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")                       -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  1.01E-05    - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                                RNKTL0
 2. MXFLAG .   0          - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                    0
 3. POFVAR . 101.0000     - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                           99.999
 4. MXORDR . 120          - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                        0.75 * MIN(NRH,NCH)

 NUMRNK ....   1          -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BY-PASSING CRITERIA 1-4 ABOVE  0

 MIDOPT ....   1          - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]               0

 ITAPE(50) .   1          - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                            1
 ITAPE(51) .   0          - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                                0
 ITAPE(55) .   0          - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                    0
 ITAPE(79) .   0          - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                          0
  MXALL ....   0          -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                            0
  MXHANK ...   0          -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                          0
  MXPDQT ...   0          -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                              0
  MXMTM ....   0          -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT            0
  MXMOMC ...   0          -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                           0
  MXDATA ...   0          -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                            0
   MXDNTM ..-999          -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79      MTIM
   MXDNSF ..   1          -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                          1
   MXDNSL ..   1          -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                        NST
   MXDNIF ..   1          -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                          1
   MXDNIL ..   1          -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                        NIC
 ITAPE(80) .   0          - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...   0          - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80          0
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 ITAPE(85) .    1          - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85          1
 ITAPE(88) .    0          - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                              0
 ITYDTA ....    3          - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                            3
 MSSCAL ....    2          - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES           2
 IREFTU ....    0          - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)       0
 T55CMI ....      1.0      - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                        1.0
 T88CMI ....      1.0      - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                        1.0

 MSTO50 ....    1          - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                       0
 MSPP50 ....    0          - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)                 1

 LOOPOP ....    0          - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                    0
  PAR(1) ... -999.00        -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                        -
  PAR(2) ... -999.00        -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                        -
  PAR(3) ... -999.00        -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                        -
  PAR(4) ... -999.00        -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                        -
  PAR(5) ... -999.00        -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                        -
*NCASES ....    1          - NO. OF CONSECUTIVE CASES TO RUN                                                                1

 IPREMC ....    0          - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                       0
 IPRHRS ....    0          - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH  0
 IPRPDQ ....    0          - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                                0
 IPRABC ....    0          - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                            0
 IPREVS ....    0          - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                                0
 IPRDTA ....    0          - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                           0
 IPRPAR ....    0          - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                           0
 MSRTOT ....    0          - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                                0

 IOMAC .....    0          - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1                 0
 ------------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS      <-- (FOOTNOTE)
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SISO2: ERA CASE 2 USING SISO

CASE NO.   1:
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D(1) =   1.17827E+02
```

SINGULAR VALUES, D():

		D(N)/D(1)	D(N)/D(N+1)	CUMULATIVE % OF VARIANCE	N
1	**********	1.00E+00	1.016	33.51376	1
2	**********	9.84E-01	2.386	65.99590	2
3	**********	4.13E-01	1.021	71.70327	3
4	**********	4.04E-01	1.067	77.17379	4
5	**********	3.79E-01	1.010	81.98274	5
6	**********	3.75E-01	1.372	86.70086	6
7	**********	2.74E-01	1.041	89.20889	7
8	**********	2.63E-01	1.008	91.52368	8
9	**********	2.61E-01	1.032	93.80141	9
10	**********	2.53E-01	1.297	95.94115	10
11	**********	1.95E-01	1.082	97.21378	11
12	**********	1.80E-01	1.553	98.30039	12
13	**********	1.16E-01	1.145	98.75101	13
14	**********	1.01E-01	1.814	99.09495	14
15	**********	5.58E-02	1.002	99.19943	15
16	**********	5.57E-02	1.077	99.30346	16
17	**********	5.17E-02	1.004	99.39318	17
18	**********	5.15E-02	1.002	99.48218	18
19	**********	5.14E-02	1.009	99.57076	19
20	**********	5.10E-02	1.017	99.65778	20
21	**********	5.01E-02	1.050	99.74198	21
22	**********	4.77E-02	1.000	99.81837	22
23	**********	4.77E-02	1.001	99.89470	23
24	**********	4.77E-02	2.337	99.97082	24
25	**********	2.04E-02	1.042	99.98474	25
26	**********	1.96E-02	3.350	99.99757	26
27	**********	5.84E-03	1.038	99.99870	27
28	**********	5.63E-03	3.873	99.99977	28
29	**********	1.45E-03	1.003	99.99985	29
30	**********	1.45E-03	1.362	99.99992	30
31	**********	1.06E-03	1.179	99.99995	31
32	**********	9.02E-04	2.039	99.99998	32
33	**********	4.42E-04	1.006	99.99998	33
34	**********	4.40E-04	1.576	100.00000	34
35	**********	2.79E-04	1.011	100.00000	35
36	**********	2.76E-04	3.413	100.00000	36
37	**********	8.09E-05	1.067	100.00000	37
38	**********	7.58E-05	1.008	100.00000	38
39	**********	7.52E-05	1.210	100.00000	39
40	**********	6.22E-05*	46.559	100.00000	40
41	XXXXXXXXXXXXXXXXXXXXXXXX	1.34E-06	1.001	100.00000	41
42	++++++++++++++++++++++++	1.33E-06	1.170	100.00000	42
43	++++++++++++++++++++++++	1.14E-06	1.017	100.00000	43
44	++++++++++++++++++++++++	1.12E-06	1.064	100.00000	44
45	++++++++++++++++++++++++	1.05E-06	1.016	100.00000	45
46	++++++++++++++++++++++++	1.04E-06	1.041	100.00000	46

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9.95E-07	1.017	100.00000	47
9.79E-07	1.014	100.00000	48
9.65E-07	1.042	100.00000	49
9.26E-07	1.009	100.00000	50
9.19E-07	1.019	100.00000	51
9.02E-07	1.057	100.00000	52
8.53E-07	1.006	100.00000	53
8.47E-07	1.000	100.00000	54
8.47E-07	1.130	100.00000	55
7.50E-07	1.079	100.00000	56
6.95E-07	1.001	100.00000	57
6.94E-07	1.035	100.00000	58
6.70E-07	1.028	100.00000	59
6.52E-07	1.069	100.00000	60
6.10E-07	1.002	100.00000	61
6.09E-07	1.017	100.00000	62
5.98E-07	1.072	100.00000	63
5.58E-07	1.015	100.00000	64
5.50E-07	1.027	100.00000	65
5.36E-07	1.008	100.00000	66
5.32E-07	1.030	100.00000	67
5.16E-07	1.005	100.00000	68
5.14E-07	1.007	100.00000	69
5.10E-07	1.016	100.00000	70
5.02E-07	1.022	100.00000	71
4.91E-07	1.019	100.00000	72
4.82E-07	1.019	100.00000	73
4.73E-07	1.045	100.00000	74
4.52E-07	1.032	100.00000	75
4.38E-07	1.032	100.00000	76
4.25E-07	1.017	100.00000	77
4.18E-07	1.015	100.00000	78
4.11E-07	1.007	100.00000	79
4.09E-07	1.009	100.00000	80
4.05E-07	1.020	100.00000	81
3.97E-07	1.003	100.00000	82
3.96E-07	1.069	100.00000	83
3.71E-07	1.007	100.00000	84
3.68E-07	1.001	100.00000	85
3.68E-07	1.037	100.00000	86
3.55E-07	1.009	100.00000	87
3.52E-07	1.018	100.00000	88
3.45E-07	1.032	100.00000	89
3.35E-07	1.001	100.00000	90
3.35E-07	1.066	100.00000	91
3.14E-07	1.005	100.00000	92
3.12E-07	1.047	100.00000	93
2.98E-07	1.005	100.00000	94
2.97E-07	1.027	100.00000	95
2.89E-07	1.071	100.00000	96
2.70E-07	1.022	100.00000	97
2.64E-07	1.016	100.00000	98
2.60E-07	1.053	100.00000	99
2.47E-07	1.032	100.00000	100
2.39E-07	1.018	100.00000	101
2.35E-07	1.005	100.00000	102
2.34E-07	1.010	100.00000	103
2.31E-07	1.039	100.00000	104
2.23E-07		100.00000	105
0.00E+00		100.00000	106
0.00E+00		100.00000	107
0.00E+00		100.00000	108
0.00E+00		100.00000	109
0.00E+00		100.00000	110
0.00E+00		100.00000	111
0.00E+00		100.00000	112
0.00E+00		100.00000	113
0.00E+00		100.00000	114
0.00E+00		100.00000	115
0.00E+00		100.00000	116
0.00E+00		100.00000	117
0.00E+00		100.00000	118
0.00E+00		100.00000	119
0.00E+00		100.00000	120

NUMERICAL RANK = 40

* SINGULAR VALUE TRUNCATION OCCURRED AT ORDER = 40 *

INPUT (REFERENCE) COORDINATE CODES:

IC NO.	COORDINATE CODE	MEAS. NO.
1	1X+	1

* NOTE: FMIN = 0.0000, SF = 100.0000, N1 = 1, ISTRIP = 1.

THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN 0.0000 & 50.0000 HZ

IDENTIFICATION RESULTS, SORTED BY FREQUENCY:

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%		EMACS >= 80% INPUT (1)	OUTPUT (1)	MPC-W	MPC-U	PRC		ARATIO	RECIP-PROCITY	MSR,%
1	1	10.000**	0.999	(1.000)	:	99.90**	99.90	:	1	1	: -999.00	-999.00	-999	:	0.200	:-999.0	21.7
2	2	15.000**	1.000	(1.000)	:	99.89**	99.89	:	1	1	: -999.00	-999.00	-999	:	0.090	:-999.0	33.3
3	3	20.200**	0.200	(0.200)	:	99.90**	99.90	:	1	1	: -999.00	-999.00	-999	:	0.522	:-999.0	31.3
4	4	20.600**	0.600	(0.600)	:	99.90**	99.90	:	1	1	: -999.00	-999.00	-999	:	0.137	:-999.0	38.1
5	5	21.000**	0.999	(1.000)	:	99.90**	99.90	:	1	1	: -999.00	-999.00	-999	:	0.034	:-999.0	38.3
6	6	21.400**	1.400	(1.400)	:	99.85**	99.85	:	1	1	: -999.00	-999.00	-999	:	0.008	:-999.0	37.2
7	7	21.800**	1.800	(1.800)	:	99.93**	99.93	:	1	1	: -999.00	-999.00	-999	:	0.002	:-999.0	36.0
8	8	25.000**	0.499	(0.499)	:	99.81**	99.81	:	1	1	: -999.00	-999.00	-999	:	0.134	:-999.0	1.9
9	9	25.501**	0.502	(0.502)	:	99.18**	99.18	:	1	1	: -999.00	-999.00	-999	:	0.127	:-999.0	0.9
10	10	25.997**	0.494	(0.499)	:	97.43**	97.43	:	1	1	: -999.00	-999.00	-999	:	0.124	:-999.0	0.4
11	11	26.501**	0.504	(0.499)	:	95.56**	95.56	:	1	1	: -999.00	-999.00	-999	:	0.119	:-999.0	0.2
12	12	27.000**	0.499	(0.497)	:	96.27**	96.27	:	1	1	: -999.00	-999.00	-999	:	0.115	:-999.0	0.1
13	13	30.000**	2.000	(2.000)	:	99.95**	99.95	:	1	1	: -999.00	-999.00	-999	:	0.000	:-999.0	24.5
14	14	31.000**	1.031	(1.031)	:	99.95**	99.95	:	1	1	: -999.00	-999.00	-999	:	0.006	:-999.0	9.0
15	15	32.000**	1.032	(1.032)	:	99.92**	99.92	:	1	1	: -999.00	-999.00	-999	:	0.005	:-999.0	8.8
16	16	33.000**	1.033	(1.033)	:	99.90**	99.90	:	1	1	: -999.00	-999.00	-999	:	0.004	:-999.0	8.5
17	17	34.000**	1.034	(1.034)	:	99.91**	99.91	:	1	1	: -999.00	-999.00	-999	:	0.004	:-999.0	8.3
18	18	35.000**	1.035	(1.035)	:	99.90**	99.90	:	1	1	: -999.00	-999.00	-999	:	0.003	:-999.0	8.0
19	19	39.999*	1.005	(1.005)	:	91.89*	91.89	:	1	1	: -999.00	-999.00	-999	:	0.002	:-999.0	0.0
20	20	44.999	0.993	(1.004)	:	75.48	75.48	:	1	1	: -999.00	-999.00	-999	:	0.001	:-999.0	0.0

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE		INITIAL PHYSICAL AMPLITUDES IC # 1	1X+
1	**10.000****	**0.999**	1X+	1	100.00	90.0	**1.0000E+00**	**90.0**
2	**15.000****	**1.000**	1X+	1	100.00	90.0	**2.0000E+00**	**-90.0**
3	**20.200****	**0.200**	1X+	1	100.00	90.0	**9.9991E-01**	**20.0**
4	**20.600****	**0.600**	1X+	1	100.00	90.0	**1.9993E+00**	**-60.0**
5	**21.000****	**0.999**	1X+	1	100.00	90.0	**2.9980E+00**	**100.0**
6	**21.400****	**1.400**	1X+	1	100.00	90.0	**4.0012E+00**	**-140.0**
7	**21.800****	**1.800**	1X+	1	100.00	90.0	**4.9986E+00**	**-180.0**
8	**25.000****	**0.499**	1X+	1	100.00	90.0	**9.9862E-02**	**0.0**
9	**25.501****	**0.502**	1X+	1	100.00	90.0	**5.0307E-02**	**20.4**
10	**25.997****	**0.494**	1X+	1	100.00	90.0	**1.9863E-02**	**38.7**
11	**26.501****	**0.504**	1X+	1	100.00	90.0	**9.9927E-03**	**60.7**
12	**27.000****	**0.499**	1X+	1	100.00	90.0	**4.9917E-03**	**80.1**
13	**30.000****	**2.000**	1X+	1	100.00	90.0	**5.1234E+00**	**90.0**
14	**31.000****	**1.031**	1X+	1	100.00	90.0	**1.0310E+00**	**31.0**
15	**32.000****	**1.032**	1X+	1	100.00	90.0	**1.0319E+00**	**32.0**
16	**33.000****	**1.033**	1X+	1	100.00	90.0	**1.0330E+00**	**33.0**
17	**34.000****	**1.034**	1X+	1	100.00	90.0	**1.0340E+00**	**34.0**
18	**35.000****	**1.035**	1X+	1	100.00	90.0	**1.0350E+00**	**35.0**

```
   19      39.999*      1.005      1X+      1   100.00   90.0   1.0035E-03   39.9
   20      44.999       0.993      1X+      1   100.00   90.0   9.9521E-04   44.9

VAX EXECUTION STATISTICS:
------------------------

COMPUTER NODENAME AND TYPE:  SDBBB,  VAXstation 3100-M76/GPX

ELAPSED:    0 00:00:32.99  CPU: 0:00:21.82  BUFIO: 73  DIRIO: 252  FAULTS: 1208

START DATE/TIME:  22-APR-1993 15:12
  END DATE/TIME:  22-APR-1993 15:13
```

9.2 MIMO

Program MIMO is similar to SISO except with general multiple-input/multiple-output (MIMO) capability. The user specifies the frequency, damping, amplitude, and phase of an arbitrary number of modes. **Mode shapes, however, are computed internally by the software.** The mode shapes are sinusoidal functions of progressively increasing frequency.[195] Noise can also be added. The noise amplitude is calculated on a function-by-function basis as a percentage of the maximum data value occurring anywhere in the response function. The noise has uniform amplitude distribution.

The program constructs free-response time histories as follows:

$$y_{ij}(t) = \sum_{k=1}^{M} A_{ik} A_{jk} S_k e^{\sigma_k t} \cos(\omega_{dk} t) + n_{ij}(t) \tag{9-2}$$

where:

$y_{ij}(t)$ = Free-response at response location i due to excitation at location j

M = No. of modes

A_{ik} = Mode shape k at response location i

A_{jk} = Mode shape k at excitation location j

S_k = Scale factor of mode k (analogous to 1/modal mass)

σ_k = Damping rate of mode k = $-\zeta_k \omega_{nk}$

ζ_k = Damping factor of mode k (fraction of critical damping)

ω_{nk} = Undamped natural frequency of mode k in rad/sec

ω_{dk} = Damped natural frequency of mode k in rad/sec = $\sqrt{1-\zeta_k^2}\,\omega_{nk}$

$n_{ij}(t)$ = Noise added to ij'th response

The parameters for program MIMO are specified using NAMELIST group &MIMOIN. The following parameters are available:

[195]Fig. 10-1 shows the first 4 mode shapes.

a-4.

```
NMODES ... NO. OF MODES
NST ..... NO. OF MEASUREMENT STATIONS (RESPONSE LOCATIONS)
NIC ..... NO. OF INITIAL CONDITIONS (EXCITATION LOCATIONS)
NTIM ..... NO. OF TIME SAMPLES TO BE GENERATED
PNOISE ... % NOISE TO ADD
SF ....... DATA SAMPLING FREQUENCY
PRANDD ... MAX. AMP. IN DEGREES OF RANDOM PHASE TO ADD TO ALL FUNCTIONS
           (TO GENERATE NON-MONOPHASE EIGENVECTORS)
FREQ() ... DAMPED NATURAL FREQUENCIES
ZETAP() .. DAMPING FACTORS IN PERCENT
AMODES().. MODAL SCALE FACTORS
INLOC() .. INPUT (EXCITATION) LOCATIONS
IPOLAR() . RESPONSE MEASUREMENT POLARITIES. THE SIGN OF IPOLAR(NS)
           INDICATES THE POLARITY OF MEASURMENT NS
NCASES ... NO. OF CASES TO GENERATE.  DIFFERENT CASES USE
           THE SAME MODAL PARAMETERS BUT DIFFERENT NOISE
           SEQUENCES.  (THIS CAPABILITY IS USED FOR MONTE CARLO RUNS.)
NPTMSR ... NO. OF DATA POINTS FOR MSR CALCULATION (MSR FOR INFO. ONLY)
T1NAMS() . TAPE1 OUTPUT FILE NAMES
```

9.2.1 Test Case MIMO1: 3 Modes, 1% Noise, Impulse Responses

Test case MIMO1 uses 3 modes with the following parameters:[196]

Frequencies:	10, 15, and 30 Hz
Damping Factors:	1, 1, and 2 percent
Amplitudes:	1, 2, and 5.1234
Phase Angles:	90, -90, and 85.5 degrees

Program MIMO generates a total of 1024 data points at a sampling frequency of 100 samples per second. There are 3 excitation locations (8, -15, and 26) and 30 response locations (1 - 30).[197] The noise amplitude is 1 percent.[198]

Run this test case by copying file RUN_MIMO1.COM from directory ERA$TESTCASES to your working directory and executing it as a standard VMS command procedure as follows:

```
COPY ERA$TESTCASES:RUN_MIMO1.COM []

@RUN_MIMO1
```

[196]These are the same parameters as in test case SISO1 (Section 9.1.1).

[197]Negative excitation locations designate reversed polarity of the excitation vector.

[198]Program MIMO calculates the noise amplitude on a function-by-function basis as a percentage of the maximum data value occurring anywhere in the response function. The noise has uniform amplitude distribution.

Here is a listing of file RUN_MIMO1.COM:

```
$! RUN_MIMO1.COM
$!
$ WRITE SYS$OUTPUT ""
$ WRITE SYS$OUTPUT "* * * BUILDING DATA FILES * * *
$ WRITE SYS$OUTPUT ""
$ WRITE SYS$OUTPUT "(PARAMETERS ECHOED ON FILE 'MIMO1.OUT')"
$ WRITE SYS$OUTPUT ""
$ SHOW TIME
$ WRITE SYS$OUTPUT ""
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO.FOR
$!
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
$!
$ STARTTIME = F$GETJPI(0,"CPUTIM")
$!
$ MIMO
MIMO1.OUT
 &MIMOIN
 T1NAMS='T1MIMO1_SH1','T1MIMO1_SH2','T1MIMO1_SH3'
 PNOISE = 1
 NIC = 3, INLOC = 8,-15,26
 NST = 30
 NTIM = 1024
 SF = 100.
 NMODES = 3
 FREQ = 10,15,30
 ZETAP  = 1,1,2
 AMODES = 1,2,5.1234
 &END
$!
$ ENDTIME = F$GETJPI(0,"CPUTIM")
$ CPUTIME = ENDTIME - STARTTIME
$ SECS      = CPUTIME/100
$ TEMP      = F$STRING(CPUTIME)
$ HUNDRETHS = F$EXTRACT( F$LENGTH(TEMP)-2, 2, TEMP)
$ TIME   = "''SECS'.''HUNDRETHS'"
$!
$ WRITE SYS$OUTPUT "MIMO EXECUTION TIME = ",''TIME'," SECS"
$ WRITE SYS$OUTPUT ""
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$TESTCASES:MIMO1.ERA []
$ @ERA MIMO1
$!
$ EXIT
```

Command procedure RUN_MIMO1.COM constructs Tape1 data files named T1MIMO1_SH1.DAT, T1MIMO1_SH2.DAT, and T1MIMO1_SH3.DAT, and then runs ERA interactively using User Input file MIMO1.ERA.

The ERA User Input file for this analysis, MIMO1.ERA, is listed below. This analysis uses a model order of 8 (IORDTU=8) although only 3 modes exist (i.e., the true order is 6). **The intent is to show that over-specification of the model size does not deteriorate the identification results.** Re-analysis using IORDTU = 6 produces essentially the same results.[199]

```
$!  MIMO1.ERA:  USER INPUT FILE FOR MIMO TEST CASE #1
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=MIMO1
$!
$ INPUT1:=MIMO1_SH1
$ INPUT2:=MIMO1_SH2
$ INPUT3:=MIMO1_SH3
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=30/
S/MRH=/MRH=300/
S/MIC=/MIC=3/
S/MST=/MST=30/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=100
 IORDTU=8,MSTO50=1
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!            [ALWAYS USE EXACTLY 5 LINES]
```

[199]User Input file MIMO1_IORDTU6.ERA in directory ERA$TESTCASES is available for this purpose.

```
$!
LINE 1 FOR USER-SUPPLIED JOB DESCRIPTION
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
MIMO1: ERA MIMO TEST CASE 1
```

All of the parameters used in constructing the input data files for Test Case MIMO1 are echoed into file MIMO1.OUT, listed below. The initial amplitudes and phase angles are printed for every input, output, and mode. These data are in physical units and can be directly compared with corresponding ERA results on output file Tape50 (file 50MIMO1.LIS).

File MIMO1.OUT

```
ECHO OF PARAMETERS USED BY MIMO TO CONSTRUCT TAPE1 DATA FILE(S).

FILE NAME: MIMO1.OUT
-------------------------------------------------------------------


FREQ() :   10.000   15.000   30.000

ZETAP() :   1.000    1.000    2.000

AMODES():   1.000    2.000    5.123

IPOLAR():       1        1        1        1        1
                1        1        1        1        1
                1        1        1        1        1
                1        1        1        1        1
                1        1        1        1        1
                1        1        1        1        1

INPUT LOCATIONS:        8      -15       26

% NOISE (% OF MAX. DATA PT.):     1.0000

INITIAL AMPLITUDES FOR INPUT NO.  1:
------------------------------------

MODE NO.:        1                    2                    3
   1    7.3326E-02  -90.0    4.0208E-01  -90.0    9.9905E-01  -90.0
   2    1.4590E-01  -90.0    7.8770E-01  -90.0    1.9065E+00  -90.0
   3    2.1698E-01  -90.0    1.1411E+00  -90.0    2.6390E+00  -90.0
   4    2.8583E-01  -90.0    1.4477E+00  -90.0    3.1295E+00  -90.0
   5    3.5174E-01  -90.0    1.6951E+00  -90.0    3.3330E+00  -90.0
   6    4.1405E-01  -90.0    1.8731E+00  -90.0    3.2307E+00  -90.0
   7    4.7211E-01  -90.0    1.9744E+00  -90.0    2.8321E+00  -90.0
   8    5.2532E-01  -90.0    1.9949E+00  -90.0    2.1738E+00  -90.0
   9    5.7315E-01  -90.0    1.9337E+00  -90.0    1.3161E+00  -90.0
  10    6.1509E-01  -90.0    1.7933E+00  -90.0    3.3762E-01  -90.0
  11    6.5072E-01  -90.0    1.5795E+00  -90.0    6.7178E-01   90.0
  12    6.7968E-01  -90.0    1.3011E+00  -90.0    1.6196E+00   90.0
  13    7.0166E-01  -90.0    9.6936E-01  -90.0    2.4188E+00   90.0
  14    7.1643E-01  -90.0    5.9796E-01  -90.0    2.9962E+00   90.0
  15    7.2386E-01  -90.0    2.0208E-01  -90.0    3.2988E+00   90.0
  16    7.2386E-01  -90.0    2.0208E-01   90.0    3.2988E+00   90.0
  17    7.1643E-01  -90.0    5.9796E-01   90.0    2.9962E+00   90.0
  18    7.0166E-01  -90.0    9.6936E-01   90.0    2.4188E+00   90.0
  19    6.7968E-01  -90.0    1.3011E+00   90.0    1.6196E+00   90.0
  20    6.5072E-01  -90.0    1.5795E+00   90.0    6.7178E-01   90.0
  21    6.1509E-01  -90.0    1.7933E+00   90.0    3.3762E-01  -90.0
  22    5.7315E-01  -90.0    1.9337E+00   90.0    1.3161E+00  -90.0
  23    5.2532E-01  -90.0    1.9949E+00   90.0    2.1738E+00  -90.0
  24    4.7211E-01  -90.0    1.9744E+00   90.0    2.8321E+00  -90.0
  25    4.1405E-01  -90.0    1.8731E+00   90.0    3.2307E+00  -90.0
  26    3.5174E-01  -90.0    1.6951E+00   90.0    3.3330E+00  -90.0
  27    2.8583E-01  -90.0    1.4477E+00   90.0    3.1295E+00  -90.0
  28    2.1698E-01  -90.0    1.1411E+00   90.0    2.6390E+00  -90.0
  29    1.4590E-01  -90.0    7.8770E-01   90.0    1.9065E+00  -90.0
  30    7.3326E-02  -90.0    4.0208E-01   90.0    9.9905E-01  -90.0
```

INITIAL AMPLITUDES FOR INPUT NO. 2:

MODE NO.:	1		2		3	
1	1.0104E-01	90.0	4.0730E-02	90.0	1.5161E+00	-90.0
2	2.0104E-01	90.0	7.9793E-02	90.0	2.8931E+00	-90.0
3	2.9898E-01	90.0	1.1559E-01	90.0	4.0047E+00	-90.0
4	3.9385E-01	90.0	1.4665E-01	90.0	4.7491E+00	-90.0
5	4.8468E-01	90.0	1.7171E-01	90.0	5.0578E+00	-90.0
6	5.7054E-01	90.0	1.8974E-01	90.0	4.9027E+00	-90.0
7	6.5054E-01	90.0	2.0000E-01	90.0	4.2978E+00	-90.0
8	7.2386E-01	90.0	2.0208E-01	90.0	3.2988E+00	-90.0
9	7.8976E-01	90.0	1.9588E-01	90.0	1.9971E+00	-90.0
10	8.4756E-01	90.0	1.8166E-01	90.0	5.1235E-01	-90.0
11	8.9665E-01	90.0	1.6000E-01	90.0	1.0194E+00	90.0
12	9.3655E-01	90.0	1.3180E-01	90.0	2.4577E+00	90.0
13	9.6683E-01	90.0	9.8194E-02	90.0	3.6706E+00	90.0
14	9.8720E-01	90.0	6.0572E-02	90.0	4.5468E+00	90.0
15	9.9743E-01	90.0	2.0470E-02	90.0	5.0059E+00	90.0
16	9.9743E-01	90.0	2.0470E-02	-90.0	5.0059E+00	90.0
17	9.8720E-01	90.0	6.0572E-02	-90.0	4.5468E+00	90.0
18	9.6683E-01	90.0	9.8194E-02	-90.0	3.6706E+00	90.0
19	9.3655E-01	90.0	1.3180E-01	-90.0	2.4577E+00	90.0
20	8.9665E-01	90.0	1.6000E-01	-90.0	1.0194E+00	90.0
21	8.4755E-01	90.0	1.8166E-01	-90.0	5.1235E-01	-90.0
22	7.8976E-01	90.0	1.9588E-01	-90.0	1.9971E+00	-90.0
23	7.2386E-01	90.0	2.0208E-01	-90.0	3.2988E+00	-90.0
24	6.5054E-01	90.0	2.0000E-01	-90.0	4.2978E+00	-90.0
25	5.7053E-01	90.0	1.8974E-01	-90.0	4.9027E+00	-90.0
26	4.8468E-01	90.0	1.7171E-01	-90.0	5.0578E+00	-90.0
27	3.9385E-01	90.0	1.4665E-01	-90.0	4.7491E+00	-90.0
28	2.9898E-01	90.0	1.1559E-01	-90.0	4.0047E+00	-90.0
29	2.0104E-01	90.0	7.9793E-02	-90.0	2.8931E+00	-90.0
30	1.0104E-01	90.0	4.0730E-02	-90.0	1.5161E+00	-90.0

INITIAL AMPLITUDES FOR INPUT NO. 3:

MODE NO.:	1		2		3	
1	4.9097E-02	-90.0	3.4166E-01	90.0	1.5318E+00	-90.0
2	9.7691E-02	-90.0	6.6934E-01	90.0	2.9231E+00	-90.0
3	1.4528E-01	-90.0	9.6961E-01	90.0	4.0463E+00	-90.0
4	1.9138E-01	-90.0	1.2302E+00	90.0	4.7983E+00	-90.0
5	2.3552E-01	-90.0	1.4404E+00	90.0	5.1103E+00	-90.0
6	2.7724E-01	-90.0	1.5916E+00	90.0	4.9535E+00	-90.0
7	3.1611E-01	-90.0	1.6777E+00	90.0	4.3424E+00	-90.0
8	3.5174E-01	-90.0	1.6951E+00	90.0	3.3330E+00	-90.0
9	3.8376E-01	-90.0	1.6431E+00	90.0	2.0178E+00	-90.0
10	4.1185E-01	-90.0	1.5238E+00	90.0	5.1766E-01	-90.0
11	4.3571E-01	-90.0	1.3422E+00	90.0	1.0300E+00	90.0
12	4.5509E-01	-90.0	1.1056E+00	90.0	2.4832E+00	90.0
13	4.6981E-01	-90.0	8.2370E-01	90.0	3.7086E+00	90.0
14	4.7971E-01	-90.0	5.0811E-01	90.0	4.5939E+00	90.0
15	4.8468E-01	-90.0	1.7171E-01	90.0	5.0578E+00	90.0
16	4.8468E-01	-90.0	1.7171E-01	-90.0	5.0578E+00	90.0
17	4.7971E-01	-90.0	5.0811E-01	-90.0	4.5939E+00	90.0
18	4.6981E-01	-90.0	8.2370E-01	-90.0	3.7086E+00	90.0
19	4.5509E-01	-90.0	1.1056E+00	-90.0	2.4832E+00	90.0
20	4.3571E-01	-90.0	1.3422E+00	-90.0	1.0300E+00	90.0
21	4.1185E-01	-90.0	1.5238E+00	-90.0	5.1766E-01	-90.0
22	3.8376E-01	-90.0	1.6431E+00	-90.0	2.0179E+00	-90.0
23	3.5174E-01	-90.0	1.6951E+00	-90.0	3.3330E+00	-90.0
24	3.1611E-01	-90.0	1.6777E+00	-90.0	4.3424E+00	-90.0
25	2.7724E-01	-90.0	1.5916E+00	-90.0	4.9535E+00	-90.0
26	2.3552E-01	-90.0	1.4404E+00	-90.0	5.1103E+00	-90.0
27	1.9138E-01	-90.0	1.2302E+00	-90.0	4.7983E+00	-90.0
28	1.4528E-01	-90.0	9.6961E-01	-90.0	4.0463E+00	-90.0
29	9.7691E-02	-90.0	6.6934E-01	-90.0	2.9231E+00	-90.0
30	4.9097E-02	-90.0	3.4166E-01	-90.0	1.5318E+00	-90.0

USING THE FIRST 100 TIME SAMPLES,
MODAL STRENGTH RATIONS (MSR) &
MODAL SIGNAL-TO-NOISE RATIOS (RMS) ARE:

	FREQ.	MSR,%	SNR
1	10.000	28.360	14.420
2	15.000	49.989	25.416
3	30.000	81.847	41.614

The ERA identification results appear on output file 50MIMO1.LIS shown below. Singular-value truncation occurred at Order = 8 as specified with parameter IORDTU in

Field 4 of the User Input file. **All modal parameters are well identified.** The ERA analysis required approximately 6 seconds of CPU time on the author's VaxStation 3100 computer.

File 50MIMO1.LIS

```
* * * ERA -- VERSION 931216 * * *


LINE 1 FOR USER-SUPPLIED JOB DESCRIPTION
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
MIMO1: ERA MIMO TEST CASE 1


TAPE1 FILE NAMES:
----------------
   1. [ERA.TESTCASES]T1MIMO1_SH1.DAT
   2. [ERA.TESTCASES]T1MIMO1_SH2.DAT
   3. [ERA.TESTCASES]T1MIMO1_SH3.DAT

ANALYSIS PARAMETERS:                                                                                                DEFAULT
--------------------                                                                                                VALUE
                  (MAX)                                                                                             -------
 NCH ....... 30 (   30)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                            MCH
 NRH ....... 300 (  300)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                           MRH
 NIC .......  3 (    3)  - NO. OF INITIAL CONDITIONS (INPUTS)                                                       MIC
 NST .......  30 (   30)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                             MST
*NTIM ......  38 ( 1024)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)          -

 SF ........   100.000     - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                          -
*WINDOW ....     0.370     - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                               -
 FMIN ......     0.000     - FMIN OF DATA (FOR "ZOOMED" DATA)                                                     0.0

 FR1FIR ....  -999.000     - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                 -
 FR2FIR ....  -999.000     - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                 -
 IORFIR ....  50           - ORDER OF BANDPASS FIR FILTER                                                          50

 NSFRST ....  1            - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                         1
 NSFLAG() ..               - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]  ALL 1
          1111111111 1111111111 1111111111
*NSTBOT ....  30           - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                  NST

 NGENTH ....  0            - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)  0
*NSTDTA ....  30           - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                           -

 N1 ........  1            - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                        1
 N2 ........  1            - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                            1
 N3 ........  1            - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                            1
 N2LAST ....  10           - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                     10
 N3LAST ....  10           - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                     10

 NSKIP .....  0            - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                 0
 ISTRIP ....  1            - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                 1
 ICAS85 ....  1            - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                          1
 DATABW ....  -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1  -

 MODELC ....  0            - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 MODELD ....  0            - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 NOAD79 ....  0            - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)  0

*RNKTL0 ....  1.80E-05     - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)                SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....  8            - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")                   -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  0.00E+00     - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                            RNKTL0
 2. MXFLAG .  0            - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                0
 3. POFVAR . 101.0000      - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                        99.999
 4. MXORDR .  30           - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                      0.75 * MIN(NRH,NCH)

 NUMRNK ....  0            -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BY-PASSING CRITERIA 1-4 ABOVE  0

 MIDOPT ....  0            - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]           0

 ITAPE(50) .  1            - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                        1
 ITAPE(51) .  0            - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                            0
 ITAPE(55) .  0            - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                0
 ITAPE(79) .  1            - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                      0
  MXALL ....  0            -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                        0
  MXHANK ...  0            -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                      0
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  MXPDQT ...    0          -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                                  0
  MXMTM ....    0          -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT               0
  MXMOMC ...    0          -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                               0
  MXDATA ...    0          -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                                0
   MXDNTM ..-999           -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79          MTIM
   MXDNSF ..   1           -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                             1
   MXDNSL ..  30           -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                           NST
   MXDNIF ..   1           -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                             1
   MXDNIL ..   3           -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                           NIC
 ITAPE(80) .   0           - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...   0           - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80              0
 ITAPE(85) .   1           - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85         1
 ITAPE(88) .   0           - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                            0
 ITYDTA ....   3           - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                          3
 MSSCAL ....   2           - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES         2
 IREFTU ....   0           - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)     0
 T55CMI ....     1.0       - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                      1.0
 T88CMI ....     1.0       - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                      1.0

 MSTO50 ....   1           - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                       0
 MSPP50 ....   1           - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)                 1

 LOOPOP ....   0           - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                    0
  PAR(1) ... -999.00       -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                        -
  PAR(2) ... -999.00       -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                        -
  PAR(3) ... -999.00       -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                        -
  PAR(4) ... -999.00       -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                        -
  PAR(5) ... -999.00       -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                        -
*NCASES ....   1           - NO. OF CONSECUTIVE CASES TO RUN                                                                1

 IPREMC ....   0           - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                       0
 IPRHRS ....   0           - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH  0
 IPRPDQ ....   0           - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                                0
 IPRABC ....   0           - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                            0
 IPREVS ....   0           - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                                0
 IPRDTA ....   0           - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                           0
 IPRPAR ....   0           - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                           0
 MSRTOT ....   0           - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                                0

 IOMAC .....   0           - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1                 0
 ------------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ------------------------------------------------------------------


MIMO1: ERA MIMO TEST CASE 1

CASE NO.   1:
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D(1) =   1.19102E+02

                                                                                                  CUMULATIVE
                                                                                                    % OF
SINGULAR VALUES, D():                                                          D(N)/D(1)  D(N)/D(N+1) VARIANCE   N
  1 ********************************************************************************************** 1.00E+00     1.197  47.68030   1
  2 ******************************************************************************************    8.35E-01     1.854  80.94191   2
  3 ************************************************************************************          4.51E-01     1.325  90.62115   3
  4 ********************************************************************************              3.40E-01     1.614  96.13318   4
  5 ************************************************************************                      2.11E-01     1.102  98.24877   5
  6 ********************************************************************                          1.91E-01    48.608  99.98996   6
  7 **********                                                                                    3.93E-03     1.051  99.99069   7
  8 *********                                                                                     3.74E-03     1.028  99.99137   8<
  9 +++++++++                                                                                     3.64E-03     1.015  99.99200   9
 10 +++++++++                                                                                     3.59E-03     1.044  99.99261  10
 11 ++++++++                                                                                      3.44E-03     1.013  99.99317  11
 12 ++++++++                                                                                      3.39E-03     1.013  99.99372  12
 13 ++++++++                                                                                      3.35E-03     1.031  99.99426  13
 14 +++++++                                                                                       3.25E-03     1.032  99.99477  14
 15 +++++++                                                                                       3.15E-03     1.020  99.99524  15
 16 +++++++                                                                                       3.09E-03     1.007  99.99569  16
 17 +++++++                                                                                       3.07E-03     1.099  99.99614  17
 18 +++++                                                                                         2.79E-03     1.004  99.99651  18
 19 +++++                                                                                         2.78E-03     1.004  99.99688  19
 20 +++++                                                                                         2.77E-03     1.025  99.99725  20
 21 +++++                                                                                         2.70E-03     1.015  99.99760  21
 22 ++++                                                                                          2.66E-03     1.041  99.99793  22
 23 ++++                                                                                          2.56E-03     1.014  99.99825  23
 24 ++++                                                                                          2.52E-03     1.010  99.99855  24
 25 ++++                                                                                          2.50E-03     1.051  99.99884  25
 26 +++                                                                                           2.38E-03     1.027  99.99911  26
 27 ++                                                                                            2.31E-03     1.049  99.99937  27
 28 ++                                                                                            2.21E-03     1.065  99.99960  28
 29 +                                                                                             2.07E-03     1.026  99.99980  29
 30 +                                                                                             2.02E-03            100.00000  30

          *  SINGULAR VALUE TRUNCATION OCCURRED AT ORDER =   8  *
```

INPUT (REFERENCE) COORDINATE CODES:

IC NO.	COORDINATE CODE	MEAS. NO.
1	8X+	8
2	15X-	15
3	26X+	26

* NOTE: FMIN = 0.0000, SF = 100.0000, N1 = 1, ISTRIP = 1.

THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN 0.0000 & 50.0000 HZ

IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (3)	OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	3	29.999**	1.993	(1.990)	98.83**	98.83	3	30	100.00	100.00	999	0.259	100.0	90.1
2	2	15.001**	0.971	(0.987)	98.02**	98.03	3	30	99.98	99.94	995	0.715	100.0	38.8
3	1	9.994**	1.042	(0.942)	95.83**	95.87	3	30	99.96	99.90	992	0.808	100.0	20.0

IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (3)	OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	3	29.999**	1.993	(1.990)	98.83**	98.83	3	30	100.00	100.00	999	0.259	100.0	90.1
2	2	15.001**	0.971	(0.987)	98.02**	98.03	3	30	99.98	99.94	995	0.715	100.0	38.8
3	1	9.994**	1.042	(0.942)	95.83**	95.87	3	30	99.96	99.90	992	0.808	100.0	20.0

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

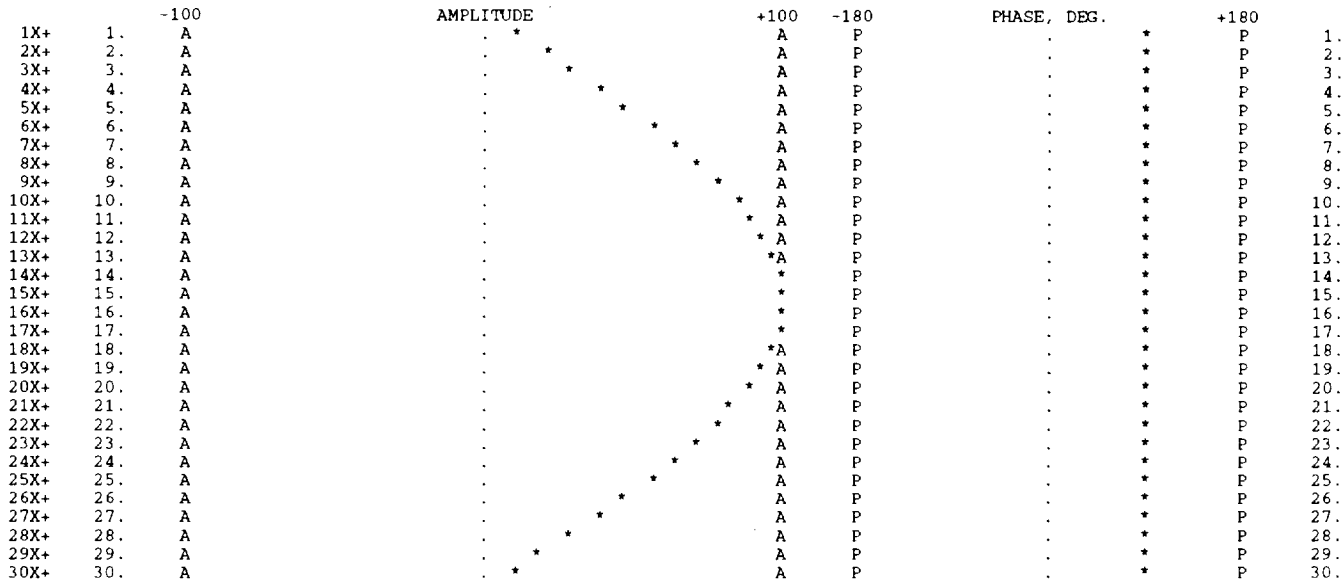
E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (3)	OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	9.994**	1.042	(0.942)	95.83**	95.87	3	30	99.96	99.90	992	0.808	100.0	20.0
2	2	15.001**	0.971	(0.987)	98.02**	98.03	3	30	99.98	99.94	995	0.715	100.0	38.8
3	3	29.999**	1.993	(1.990)	98.83**	98.83	3	30	100.00	100.00	999	0.259	100.0	90.1

EIGENVALUE NO. 1 FREQUENCY = 9.994 HZ

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE		INITIAL PHYSICAL AMPLITUDES IC # 1	8X+	IC # 2	15X-	IC # 3	26X+
1	9.994**	1.042	1X+	1	9.91	89.7	7.2310E-02	-90.6	9.9215E-02	89.7	4.8048E-02	-90.3
			2X+	2	20.26	91.2	1.4780E-01	-89.1	2.0280E-01	91.2	9.8211E-02	-88.8
			3X+	3	30.68	92.0	2.2389E-01	-88.3	3.0719E-01	91.9	1.4877E-01	-88.1
			4X+	4	38.72	90.2	2.8257E-01	-90.1	3.8771E-01	90.2	1.8776E-01	-89.9
			5X+	5	47.67	89.8	3.4784E-01	-90.5	4.7726E-01	89.8	2.3113E-01	-90.2
			6X+	6	57.55	90.2	4.1996E-01	-90.1	5.7622E-01	90.2	2.7905E-01	-89.8
			7X+	7	63.61	89.8	4.6419E-01	-90.5	6.3691E-01	89.8	3.0844E-01	-90.3
			8X+	8	71.96	89.5	5.2513E-01	-90.7	7.2051E-01	89.5	3.4893E-01	-90.5
			9X+	9	79.14	89.8	5.7750E-01	-90.5	7.9238E-01	89.8	3.8373E-01	-90.3
			10X+	10	84.31	89.7	6.1525E-01	-90.5	8.4417E-01	89.7	4.0882E-01	-90.3
			11X+	11	89.72	89.8	6.5472E-01	-90.5	8.9833E-01	89.8	4.3504E-01	-90.2
			12X+	12	92.95	90.2	6.7830E-01	-90.1	9.3067E-01	90.2	4.5071E-01	-89.8
			13X+	13	96.70	90.8	7.0564E-01	-89.5	9.6820E-01	90.8	4.6888E-01	-89.2
			14X+	14	98.08	90.4	7.1567E-01	-89.9	9.8195E-01	90.4	4.7554E-01	-89.7
			15X+	15	100.00	90.6	7.2971E-01	-89.7	1.0012E+00	90.6	4.8487E-01	-89.4

16X+	16	99.23	90.5	7.2410E-01	-89.8	9.9352E-01	90.5	4.8114E-01	-89.5
17X+	17	98.85	90.4	7.2129E-01	-89.9	9.8967E-01	90.4	4.7928E-01	-89.6
18X+	18	95.12	89.6	6.9412E-01	-90.7	9.5239E-01	89.6	4.6122E-01	-90.5
19X+	19	94.43	89.3	6.8904E-01	-91.0	9.4542E-01	89.3	4.5785E-01	-90.8
20X+	20	89.14	89.7	6.5050E-01	-90.6	8.9253E-01	89.6	4.3224E-01	-90.4
21X+	21	83.82	89.6	6.1163E-01	-90.7	8.3921E-01	89.5	4.0641E-01	-90.5
22X+	22	78.67	89.5	5.7408E-01	-90.8	7.8768E-01	89.5	3.8146E-01	-90.5
23X+	23	72.85	89.8	5.3158E-01	-90.5	7.2936E-01	89.8	3.5322E-01	-90.2
24X+	24	64.47	89.9	4.7041E-01	-90.4	6.4544E-01	89.8	3.1257E-01	-90.2
25X+	25	56.34	90.7	4.1109E-01	-89.6	5.6405E-01	90.7	2.7316E-01	-89.3
26X+	26	47.99	87.4	3.5016E-01	-92.8	4.8044E-01	87.4	2.3267E-01	-92.6
27X+	27	38.85	90.0	2.8350E-01	-90.3	3.8898E-01	90.0	1.8838E-01	-90.1
28X+	28	30.04	91.6	2.1922E-01	-88.7	3.0079E-01	91.6	1.4567E-01	-88.5
29X+	29	19.74	87.7	1.4404E-01	-92.6	1.9763E-01	87.7	9.5707E-02	-92.3
30X+	30	9.97	91.2	7.2785E-02	-89.1	9.9867E-02	91.2	4.8363E-02	-88.8

NORMALIZED MODAL PARTICIPATION FACTOR(S): 72.88 -0.3 100.00 0.0 48.43 0.0



EIGENVALUE NO. 2 FREQUENCY = 15.001 HZ

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE		INITIAL PHYSICAL AMPLITUDES IC # 1	8X+	IC # 2	15X-	IC # 3	26X+
2	15.001**	0.971	1X+	1	19.96	-90.1	3.9788E-01	-90.1	4.0846E-02	90.3	3.3687E-01	89.9
			2X+	2	39.44	-89.7	7.8632E-01	-89.6	8.0725E-02	90.7	6.6576E-01	90.3
			3X+	3	56.84	-90.2	1.1333E+00	-90.1	1.1635E-01	90.2	9.5956E-01	89.8
			4X+	4	72.51	-89.3	1.4456E+00	-89.2	1.4841E-01	91.1	1.2240E+00	90.7
			5X+	5	85.27	-89.5	1.7001E+00	-89.4	1.7454E-01	90.9	1.4395E+00	90.5
			6X+	6	93.94	-90.8	1.8729E+00	-90.7	1.9227E-01	89.6	1.5857E+00	89.2
			7X+	7	98.24	-89.8	1.9587E+00	-89.7	2.0109E-01	90.6	1.6584E+00	90.2
			8X+	8	99.77	-89.7	1.9891E+00	-89.6	2.0420E-01	90.7	1.6841E+00	90.3
			9X+	9	97.00	-90.1	1.9338E+00	-90.0	1.9853E-01	90.3	1.6373E+00	89.9
			10X+	10	89.83	-90.0	1.7909E+00	-89.9	1.8386E-01	90.4	1.5163E+00	90.0
			11X+	11	79.45	-90.4	1.5839E+00	-90.4	1.6261E-01	90.0	1.3411E+00	89.5
			12X+	12	65.03	-90.2	1.2966E+00	-90.2	1.3311E-01	90.2	1.0978E+00	89.7
			13X+	13	48.59	-90.9	9.6873E-01	-90.9	9.9451E-02	89.5	8.2021E-01	89.1
			14X+	14	29.81	-90.7	5.9441E-01	-90.7	6.1023E-02	89.7	5.0328E-01	89.2
			15X+	15	9.82	-91.8	1.9583E-01	-91.8	2.0104E-02	88.6	1.6581E-01	88.1
			16X+	16	10.01	92.1	1.9956E-01	92.2	2.0487E-02	-87.5	1.6896E-01	-87.9
			17X+	17	29.45	88.8	5.8724E-01	88.8	6.0287E-02	-90.8	4.9721E-01	-91.3
			18X+	18	49.05	89.9	9.7791E-01	90.0	1.0039E-01	-89.7	8.2798E-01	-90.1
			19X+	19	65.48	89.5	1.3055E+00	89.6	1.3402E-01	-90.1	1.1053E+00	-90.5
			20X+	20	79.45	90.2	1.5840E+00	90.2	1.6261E-01	-89.4	1.3411E+00	-89.9
			21X+	21	90.20	90.2	1.7983E+00	90.2	1.8462E-01	-89.4	1.5226E+00	-89.9
			22X+	22	96.95	90.1	1.9329E+00	90.1	1.9844E-01	-89.5	1.6366E+00	-89.9
			23X+	23	100.00	90.3	1.9937E+00	90.3	2.0468E-01	-89.3	1.6881E+00	-89.8
			24X+	24	99.08	89.8	1.9754E+00	89.8	2.0279E-01	-89.9	1.6725E+00	-90.3
			25X+	25	93.79	89.6	1.8699E+00	89.6	1.9196E-01	-90.0	1.5832E+00	-90.5
			26X+	26	85.33	90.1	1.7013E+00	90.1	1.7466E-01	-89.5	1.4404E+00	-90.0
			27X+	27	72.88	90.0	1.4530E+00	90.1	1.4916E-01	-89.6	1.2302E+00	-90.0
			28X+	28	57.65	90.4	1.1494E+00	90.5	1.1799E-01	-89.2	9.7315E-01	-89.6
			29X+	29	39.69	90.3	7.9124E-01	90.3	8.1230E-02	-89.3	6.6993E-01	-89.8

			30X+	30	20.22	90.6	4.0315E-01	90.6	4.1388E-02	-89.0	3.4134E-01	-89.4
		NORMALIZED MODAL PARTICIPATION FACTOR(S):					100.00	0.0	10.27	0.4	84.67	-0.1

		-100 AMPLITUDE +100	-180	PHASE, DEG.	+180	
1X+	1.	A * .	A	P * .	P	1.
2X+	2.	A * .	A	P * .	P	2.
3X+	3.	A * .	A	P * .	P	3.
4X+	4.	A * .	A	P * .	P	4.
5X+	5.	A * .	A	P * .	P	5.
6X+	6.	A * .	A	P * .	P	6.
7X+	7.	* .	A	P * .	P	7.
8X+	8.	* .	A	P * .	P	8.
9X+	9.	A* .	A	P * .	P	9.
10X+	10.	A * .	A	P * .	P	10.
11X+	11.	A * .	A	P * .	P	11.
12X+	12.	A * .	A	P * .	P	12.
13X+	13.	A * .	A	P * .	P	13.
14X+	14.	A * .	A	P * .	P	14.
15X+	15.	A * .	A	P * .	P	15.
16X+	16.	A . *	A	P .	* P	16.
17X+	17.	A . *	A	P .	* P	17.
18X+	18.	A . *	A	P .	* P	18.
19X+	19.	A . *	A	P .	* P	19.
20X+	20.	A . *	A	P .	* P	20.
21X+	21.	A . *	A	P .	* P	21.
22X+	22.	A .	*A	P .	* P	22.
23X+	23.	A .	*	P .	* P	23.
24X+	24.	A .	*	P .	* P	24.
25X+	25.	A .	* A	P .	* P	25.
26X+	26.	A .	* A	P .	* P	26.
27X+	27.	A .	* A	P .	* P	27.
28X+	28.	A .	* A	P .	* P	28.
29X+	29.	A .	* A	P .	* P	29.
30X+	30.	A .	* A	P .	* P	30.

EIGENVALUE NO. 3 FREQUENCY = 29.999 HZ

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE		INITIAL PHYSICAL AMPLITUDES IC # 1	8X+	IC # 2	15X-	IC # 3	26X+
3	29.999**	1.993	1X+	1	29.90	90.0	9.9668E-01	-90.0	1.5123E+00	-90.0	1.5271E+00	-90.0
			2X+	2	57.20	89.9	1.9063E+00	-90.1	2.8925E+00	-90.1	2.9208E+00	-90.1
			3X+	3	78.66	90.1	2.6216E+00	-89.9	3.9778E+00	-90.0	4.0167E+00	-89.9
			4X+	4	94.18	89.9	3.1389E+00	-90.1	4.7627E+00	-90.1	4.8093E+00	-90.1
			5X+	5	99.75	90.2	3.3245E+00	-89.9	5.0442E+00	-89.9	5.0937E+00	-89.9
			6X+	6	96.95	90.0	3.2313E+00	-90.0	4.9030E+00	-90.0	4.9510E+00	-90.0
			7X+	7	84.81	90.1	2.8266E+00	-89.9	4.2888E+00	-89.9	4.3309E+00	-89.9
			8X+	8	65.23	90.0	2.1742E+00	-90.0	3.2989E+00	-90.0	3.3313E+00	-90.0
			9X+	9	39.69	89.8	1.3230E+00	-90.3	2.0074E+00	-90.3	2.0270E+00	-90.3
			10X+	10	10.07	89.9	3.3560E-01	-90.1	5.0921E-01	-90.1	5.1420E-01	-90.1
			11X+	11	20.13	-90.0	6.7088E-01	89.9	1.0179E+00	89.9	1.0279E+00	89.9
			12X+	12	48.54	-89.9	1.6177E+00	90.0	2.4546E+00	90.0	2.4786E+00	90.0
			13X+	13	72.33	-90.0	2.4106E+00	90.0	3.6577E+00	90.0	3.6935E+00	90.0
			14X+	14	89.89	-90.0	2.9960E+00	90.0	4.5458E+00	90.0	4.5904E+00	90.0
			15X+	15	98.88	-90.0	3.2957E+00	90.0	5.0005E+00	90.0	5.0495E+00	90.0
			16X+	16	98.88	-89.9	3.2954E+00	90.0	5.0002E+00	90.0	5.0492E+00	90.0
			17X+	17	89.46	-90.0	2.9817E+00	90.0	4.5242E+00	90.0	4.5685E+00	90.0
			18X+	18	72.65	-90.1	2.4214E+00	89.9	3.6740E+00	89.9	3.7100E+00	89.9
			19X+	19	48.78	-89.9	1.6258E+00	90.1	2.4668E+00	90.1	2.4910E+00	90.1
			20X+	20	20.13	-89.9	6.7074E-01	90.1	1.0177E+00	90.1	1.0277E+00	90.1
			21X+	21	10.14	89.6	3.3785E-01	-90.4	5.1263E-01	-90.4	5.1765E-01	-90.4
			22X+	22	39.40	90.1	1.3132E+00	-89.9	1.9925E+00	-89.9	2.0120E+00	-89.9
			23X+	23	65.04	89.9	2.1677E+00	-90.1	3.2891E+00	-90.1	3.3213E+00	-90.1
			24X+	24	84.72	89.9	2.8237E+00	-90.2	4.2844E+00	-90.2	4.3264E+00	-90.2
			25X+	25	96.71	89.8	3.2231E+00	-90.2	4.8905E+00	-90.2	4.9384E+00	-90.2
			26X+	26	100.00	90.0	3.3329E+00	-90.0	5.0570E+00	-90.0	5.1066E+00	-90.0
			27X+	27	93.81	90.0	3.1264E+00	-90.1	4.7438E+00	-90.1	4.7903E+00	-90.1
			28X+	28	79.27	90.0	2.6419E+00	-90.0	4.0086E+00	-90.0	4.0479E+00	-90.0
			29X+	29	56.94	90.0	1.8977E+00	-90.1	2.8795E+00	-90.1	2.9077E+00	-90.1
			30X+	30	29.96	90.1	9.9846E-01	-89.9	1.5150E+00	-89.9	1.5298E+00	-89.9
		NORMALIZED MODAL PARTICIPATION FACTOR(S):					65.27	0.0	99.03	0.0	100.00	0.0

		-100 AMPLITUDE +100	-180	PHASE, DEG.	+180	
1X+	1.	A . *	A	P .	* P	1.
2X+	2.	A . *	A	P .	* P	2.
3X+	3.	A . *	A	P .	* P	3.
4X+	4.	A . *	A	P .	* P	4.
5X+	5.	A . *	A	P .	* P	5.
6X+	6.	A . *	A	P .	* P	6.
7X+	7.	A . *	A	P .	* P	7.
8X+	8.	A . *	A	P .	* P	8.

```
 9X+    9.    A                                .          *              A     P                .          *        P      9.
10X+   10.    A                                .    *                    A     P                .          *        P     10.
11X+   11.    A                          *     .                         A     P          *     .                   P     11.
12X+   12.    A                    *           .                         A     P          *     .                   P     12.
13X+   13.    A          *                     .                         A     P          *     .                   P     13.
14X+   14.    A    *                           .                         A     P          *     .                   P     14.
15X+   15.    *                                .                         A     P          *     .                   P     15.
16X+   16.    *                                .                         A     P          *     .                   P     16.
17X+   17.    A    *                           .                         A     P          *     .                   P     17.
18X+   18.    A          *                     .                         A     P          *     .                   P     18.
19X+   19.    A                    *           .                         A     P          *     .                   P     19.
20X+   20.    A                          *     .                         A     P          *     .                   P     20.
21X+   21.    A                                .    *                    A     P                .          *        P     21.
22X+   22.    A                                .          *              A     P                .          *        P     22.
23X+   23.    A                                .                *       A     P                .          *        P     23.
24X+   24.    A                                .                   *    A     P                .          *        P     24.
25X+   25.    A                                .                     *  A     P                .          *        P     25.
26X+   26.    A                                .                     *  A     P                .          *        P     26.
27X+   27.    A                                .                     *  A     P                .          *        P     27.
28X+   28.    A                                .                  *     A     P                .          *        P     28.
29X+   29.    A                                .                *       A     P                .          *        P     29.
30X+   30.    A                                .          *             A     P                .          *        P     30.


VAX EXECUTION STATISTICS:
-------------------------

COMPUTER NODENAME AND TYPE:  SDBHR,  VAXstation 3100-M76/GPX

ELAPSED:    0 00:00:17.51  CPU: 0:00:05.80  BUFIO: 81  DIRIO: 234  FAULTS: 1056

START DATE/TIME:   7-MAR-1994 14:16
  END DATE/TIME:   7-MAR-1994 14:16
```

9.2.2 Test Case MIMO2: 3 Modes, 1% Noise, Pulse Responses

In this test case, the free response data generated by program MIMO are **assumed** to be pulse response functions (PRFs) rather than impulse response functions (IRFs) as in test case MIMO1. PRFs are the free response of a dynamic system to a unit amplitude excitation applied for 1 data-sampling period, whereas IRFs are the free response of the system to a unit-amplitude impulse (i.e., a Dirac delta function).

ERA uses PRFs to obtain discrete state-space models for control design as described in Section 2.4. See also Section 2.2 which compares continuous-time and discrete-time state-space models. Test case MIMO1 discussed previously in Section 9.2.1 assumed that the free-response data generated by program MIMO are IRFs and used the continuous-time ERA solution. Test case MIMO2 discussed in this section uses the discrete-time ERA solution.

When ERA is used to identify a discrete state-space model for control design, modal parameters are typically not of interest. The end product of the analysis is the $[A,B,C,D]$ model, Eq. 2-39. Model accuracy is evaluated by comparing measured dynamic responses with corresponding model predictions.[200] For example, predicted PRFs of the model are compared with the PRF data analyzed by ERA to generate the model.

---

[200]Good agreement of measured and predicted responses is a necessary, but not sufficient, condition for accurate modal parameters.

A discrete model [A,B,C,D] is written to ERA output file Tape79 by specifying parameter MODELD in Field 4 of the User Input file. MODELD is an acronym for "Discrete MODEL." MODELD=1 causes the ERA analysis to stop after the model is written to Tape79. In this case, the corresponding modal parameters (natural frequencies, damping, and mode shapes) are not calculated. If MODELD=2, the analysis continues and all modal parameters and accuracy indicators (EMAC, CMI, MPC-U, MPC-W, MSR, Reciprocity, ARATIO, ZETA2) are calculated in the usual manner. If MODELD=0 (the default), the continuous-time formulation is used. Test case MIMO2 uses MODELD=2. Chapter 6 describes all ERA analysis parameters.

The ERA User Input file for this test case, MIMO2.ERA, is listed below. The analysis uses a model order of 8 (IORDTU=8) although only 3 modes exist (i.e., the true order is 6). **The intent is to show that over-specification of the model size does not deteriorate the identification results.** Re-analysis using IORDTU = 6 produces essentially the same results.[201] Parameter IPREVS = 1 requests printing of the identified eigenvalues (in all possible formats). Parameters MXDATA=1, MXDNTM=50, MXDNSF=1, MXDNSL=1, MXDNIF=1, MXDNIL=1 request that 50 Tape1 data samples for Output 1-Input 1 be written to Tape79. These 50 Tape1 data samples will be compared in MATLAB with corresponding PRF predictions.

```
$!  MIMO2.ERA:  USER INPUT FILE FOR MIMO TEST CASE #2
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=MIMO2
$!
$ INPUT1:=MIMO1_SH1
$ INPUT2:=MIMO1_SH2
$ INPUT3:=MIMO1_SH3
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=30/
S/MRH=/MRH=300/
```

[201] User Input file MIMO2_IORDTU6.ERA in directory ERA$TESTCASES is available for this purpose.

```
S/MIC=/MIC=3/
S/MST=/MST=30/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                      OF AVAILABLE PARAMETERS]
$!
 SF=100,MODELD=2,IORDTU=8
 IPREVS=1
 MXDATA=1,MXDNTM=50,MXDNSF=1,MXDNSL=1,MXDNIF=1,MXDNIL=1
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!             [ALWAYS USE EXACTLY 5 LINES]
$!
SAME AS MIMO1 EXCEPT MODELD=2
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
MIMO2: ERA MIMO TEST CASE 2
```

Execute this User Input file as follows:

```
COPY ERA$TESTCASES:MIMO2.ERA []

@ERA MIMO2
```

The ERA analysis required approximately 5 seconds of CPU time on the author's VAXstation 3100 computer. Here is a summary of the identification results on output file 50MIMO2.LIS:

File 50MIMO2.LIS

```
* * * ERA -- VERSION 931216 * * *


SAME AS MIMO1 EXCEPT MODELD=2
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
MIMO2: ERA MIMO TEST CASE 2


TAPE1 FILE NAMES:
----------------
   1. []T1MIMO1_SH1.DAT
   2. []T1MIMO1_SH2.DAT
   3. []T1MIMO1_SH3.DAT

ANALYSIS PARAMETERS:                                                                                                  DEFAULT
-------------------                                                                                                    VALUE
                  (MAX)                                                                                                -------
 NCH .......  30 (   30)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                              MCH
 NRH ....... 300 (  300)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                              MRH
 NIC .......   3 (    3)  - NO. OF INITIAL CONDITIONS (INPUTS)                                                          MIC
 NST .......  30 (   30)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                                   MST
*NTIM ......  39 ( 1024)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)                 -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                                 -
*WINDOW ....     0.370    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                                      -
```

```
 FMIN ......      0.000     - FMIN OF DATA (FOR "ZOOMED" DATA)                                                              0.0

 FR1FIR ....   -999.000     - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                        -
 FR2FIR ....   -999.000     - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                        -
 IORFIR ....   50           - ORDER OF BANDPASS FIR FILTER                                                                 50

 NSFRST ....   1            - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                                1
 NSFLAG() ..                - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]      ALL 1
          1111111111 1111111111 1111111111
*NSTBOT ....   30           - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                         NST

 NGENTH ....   0            - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)   0
*NSTDTA ....   30           - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                                  -

 N1 ........   1            - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                               1
 N2 ........   1            - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                                   1
 N3 ........   1            - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                                   1
 N2LAST ....   10           - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                           10
 N3LAST ....   10           - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                           10

 NSKIP .....   0            - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                       0
 ISTRIP ....   1            - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                       1
 ICAS85 ....   1            - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                                1
 DATABW ....   -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1  -

 MODELC ....   0            - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79   0
 MODELD ....   2            - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79   0
 NOAD79 ....   0            - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)      0

*RNKTL0 ....   1.80E-05     - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)          SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....   8            - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")                          -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  0.00E+00      - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                                 RNKTL0
 2. MXFLAG .  0             - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                      0
 3. POFVAR .  101.0000      - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                             99.999
 4. MXORDR .  30            - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                    0.75 * MIN(NRH,NCH)

 NUMRNK ....   0            -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BY-PASSING CRITERIA 1-4 ABOVE     0

 MIDOPT ....   0            - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]                  0

 ITAPE(50) .   1            - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                               1
 ITAPE(51) .   0            - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                                   0
 ITAPE(55) .   0            - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                       0
 ITAPE(79) .   1            - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                             0
  MXALL ....   0            -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                               0
  MXHANK ...   0            -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                            0
  MXPDQT ...   0            -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                                0
  MXMTM ....   0            -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT             0
  MXMOMC ...   0            -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                             0
  MXDATA ...   1            -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                              0
   MXDNTM ..   50           -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79        MTIM
   MXDNSF ..   1            -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                            1
   MXDNSL ..   1            -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                          NST
   MXDNIF ..   1            -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                            1
   MXDNIL ..   1            -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                          NIC
 ITAPE(80) .   0            - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...   0            - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80            0
 ITAPE(85) .   1            - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85       1
 ITAPE(88) .   0            - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                           0
 ITYDTA ....   3            - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                         3
 MSSCAL ....   2            - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES        2
 IREFTU ....   0            - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)    0
 T55CMI ....     1.0        - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                     1.0
 T88CMI ....     1.0        - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                     1.0

 MSTO50 ....   0            - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                      0
 MSPP50 ....   1            - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)                1

 LOOPOP ....   0            - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                   0
  PAR(1) ... -999.00        -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                       -
  PAR(2) ... -999.00        -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                       -
  PAR(3) ... -999.00        -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                       -
  PAR(4) ... -999.00        -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                       -
  PAR(5) ... -999.00        -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                       -
*NCASES ....   1            - NO. OF CONSECUTIVE CASES TO RUN                                                               1

 IPREMC ....   0            - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                      0
 IPRHRS ....   0            - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH  0
 IPRPDQ ....   0            - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                               0
 IPRABC ....   0            - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                           0
 IPREVS ....   1            - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                               0
 IPRDTA ....   0            - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                          0
 IPRPAR ....   0            - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                          0
 MSRTOT ....   0            - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                               0

 IOMAC .....   0            - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1               0
 ---------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
```

MIMO2: ERA MIMO TEST CASE 2

CASE NO. 1:

D(1) = 1.19609E+02

SINGULAR VALUES, D():

		D(N)/D(1)	D(N)/D(N+1)	CUMULATIVE % OF VARIANCE	N
1	**********	1.00E+00	1.302	50.77026	1
2	**********	7.68E-01	1.869	80.73302	2
3	**********	4.11E-01	1.134	89.30943	3
4	**********	3.63E-01	1.800	95.98351	4
5	**********	2.01E-01	1.029	98.04297	5
6	**********	1.96E-01	50.744	99.98940	6
7	*********	3.86E-03	1.038	99.99016	7
8	*********	3.72E-03	1.022	99.99086	8<
9	+++++++++	3.64E-03	1.010	99.99153	9
10	++++++++	3.60E-03	1.018	99.99219	10
11	++++++++	3.54E-03	1.038	99.99282	11
12	++++++++	3.41E-03	1.066	99.99342	12
13	+++++++	3.20E-03	1.004	99.99393	13
14	+++++++	3.19E-03	1.025	99.99445	14
15	++++++	3.11E-03	1.009	99.99494	15
16	++++++	3.08E-03	1.040	99.99541	16
17	++++++	2.96E-03	1.025	99.99586	17
18	+++++	2.89E-03	1.019	99.99628	18
19	+++++	2.84E-03	1.036	99.99669	19
20	++++	2.74E-03	1.013	99.99707	20
21	++++	2.70E-03	1.026	99.99744	21
22	++++	2.63E-03	1.025	99.99780	22
23	+++	2.57E-03	1.013	99.99813	23
24	+++	2.54E-03	1.056	99.99846	24
25	+++	2.40E-03	1.014	99.99875	25
26	++	2.37E-03	1.030	99.99903	26
27	++	2.30E-03	1.051	99.99931	27
28	+	2.19E-03	1.022	99.99954	28
29	+	2.15E-03	1.027	99.99978	29
30	+	2.09E-03		100.00000	30

* SINGULAR VALUE TRUNCATION OCCURRED AT ORDER = 8 *

SIGMA = REAL PART OF S-PLANE EIGENVALUE, RAD/SEC
WD = IMAG PART OF S-PLANE EIGENVALUE, RAD/SEC
WN = MAGNITUDE OF S-PLANE EIGENVALUE, RAD/SEC
SIGMA-HZ = DAMPING RATE, HZ (SIGMA/2PI)
FD-HZ = DAMPED NATURAL FREQUENCY, HZ (WD/2PI)
FN-HZ = UNDAMPED NATURAL FREQUENCY, HZ (WN/2PI)
ZETA-% = DAMPING FACTOR (C/CC), %
ZREAL = REAL PART OF Z-PLANE EIGENVALUE, DIMENSIONLESS
ZIMAG = IMAG PART OF Z-PLANE EIGENVALUE, "
ZMAG = MAGNITUDE OF Z-PLANE EIGENVALUE, "
ZPHSD = PHASE ANG OF Z-PLANE EIGENVALUE, DEG

EIGENVALUES:

	SIGMA	WD	WN	SIGMA-HZ	FD-HZ	FN-HZ	ZETA-%	ZREAL	ZIMAG	ZMAG	ZPHSD
1	-5.9961E+01	0.0000E+00	5.9961E+01	-9.543E+00	0.00000E+00	9.54315E+00	1.000E+02	5.490E-01	0.000E+00	5.490E-01	0.000E+00
2	-9.5075E+01	3.1416E+02	3.2823E+02	-1.513E+01	5.00000E+01	5.22395E+01	2.897E+01	-3.864E-01	0.000E+00	3.864E-01	1.800E+02
3	-6.3249E-01	6.2821E+01	6.2824E+01	-1.007E-01	9.99831E+00	9.99882E+00	1.007E+00	8.040E-01	5.840E-01	9.937E-01	3.599E+01
4	-6.3249E-01	-6.2821E+01	6.2824E+01	-1.007E-01	-9.99831E+00	9.99882E+00	1.007E+00	8.040E-01	-5.840E-01	9.937E-01	-3.599E+01
5	-9.4310E-01	9.4262E+01	9.4267E+01	-1.501E-01	1.50023E+01	1.50031E+01	1.000E+00	5.822E-01	8.015E-01	9.906E-01	5.401E+01
6	-9.4310E-01	-9.4262E+01	9.4267E+01	-1.501E-01	-1.50023E+01	1.50031E+01	1.000E+00	5.822E-01	-8.015E-01	9.906E-01	-5.401E+01
7	-3.7652E+00	1.8849E+02	1.8853E+02	-5.993E-01	2.99990E+01	3.00050E+01	1.997E+00	-2.975E-01	9.159E-01	9.630E-01	1.080E+02
8	-3.7652E+00	-1.8849E+02	1.8853E+02	-5.993E-01	-2.99990E+01	3.00050E+01	1.997E+00	-2.975E-01	-9.159E-01	9.630E-01	-1.080E+02

INPUT (REFERENCE) COORDINATE CODES:

IC NO.	COORDINATE CODE	MEAS. NO.
1	8X+	8
2	15X-	15
3	26X+	26

```
* NOTE: FMIN =    0.0000, SF =   100.0000, N1 =  1, ISTRIP =  1.
  THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN      0.0000 &     50.0000 HZ

IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):
```

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (3)	OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	3	29.999**	1.997	(1.989)	98.70**	98.70	3	30	100.00	100.00	999	0.259	100.0	89.7
2	2	15.002**	1.000	(0.975)	97.87**	97.89	3	30	99.98	99.89	995	0.718	100.0	38.8
3	1	9.998**	1.007	(0.993)	97.09**	97.14	3	30	99.95	99.87	992	0.799	100.0	20.4

```
IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):
```

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (3)	OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	3	29.999**	1.997	(1.989)	98.70**	98.70	3	30	100.00	100.00	999	0.259	100.0	89.7
2	2	15.002**	1.000	(0.975)	97.87**	97.89	3	30	99.98	99.89	995	0.718	100.0	38.8
3	1	9.998**	1.007	(0.993)	97.09**	97.14	3	30	99.95	99.87	992	0.799	100.0	20.4

```
IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):
```

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (3)	OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	9.998**	1.007	(0.993)	97.09**	97.14	3	30	99.95	99.87	992	0.799	100.0	20.4
2	2	15.002**	1.000	(0.975)	97.87**	97.89	3	30	99.98	99.89	995	0.718	100.0	38.8
3	3	29.999**	1.997	(1.989)	98.70**	98.70	3	30	100.00	100.00	999	0.259	100.0	89.7

```
VAX EXECUTION STATISTICS:

 COMPUTER NODENAME AND TYPE:  SDBHR,  VAXstation 3100-M76/GPX

 ELAPSED:    0 00:00:11.23  CPU: 0:00:05.27  BUFIO: 77  DIRIO: 165  FAULTS: 1078

 START DATE/TIME:  16-MAR-1994 09:18
   END DATE/TIME:  16-MAR-1994 09:18
```

When ERA is used to identify a discrete state-space model for control design, modal parameters are typically <u>not</u> of interest. The end product of the analysis is the $[A,B,C,D]$ model, Eq. 2-39. Model accuracy is evaluated by comparing measured dynamic responses with corresponding model predictions.[202] For example, predicted PRFs of the model are calculated as follows:

[202]Good agreement of measured and predicted responses is a necessary, but not sufficient, condition for accurate modal parameters.

$$\hat{Y}(k) = \begin{cases} D & for\ k = 0 \\ CA^{k-1}B & for\ k = 1,2,3,\cdots \end{cases} \tag{9-3}$$

using the identified $[A,B,C,D]$ matrices. These predictions are compared with the measured PRFs, $Y(k)$, that were analyzed by ERA to generate the model.

Postprocessor program ERAP10B calculates PRFs of discrete-time models according to Eq. 9-3.[203] The [A,B,C,D] matrices are read from ERA output file Tape79 (79MIMO2.DAT). Copy and execute GO Input file P10B_MIMO2.COM as follows:

```
COPY ERA$GO:P10B_MIMO2.COM []

GO P10B_MIMO2
```

Here is a listing of file P10B_MIMO2.COM:

```
$! P10B_MIMO2.COM
$!
$ RUN ERA$EXES:ERAP10B
79MIMO2    TAPE79 FILE
1  1=COMPUTE PRFS, 2=EXCITATION HISTORIES PROVIDED, 3=COMPUTE IRFS
T1TEMP     FILE TO RECEIVE COMPUTED RESPONSES (TAPE1 FORMAT)
1      CHANGE ALL NEG. DAMPING TO ZERO? 1=YES
1      PRINT OUT Z-PLANE EIGENVALUES/ 1=YES
1      COMPARE CALCULATE RESPONSES WITH MEASURED RESPONSES (RMS) ?  1=YES
T1MIMO1_SH1    FILE CONTAINING MEASURED RESPONSES
1      STARTING RECORD NO. ON THIS FILE FOR THE MEASURED RESPONSES
0      WRITE RMS DIFFERENCES TO A FILE? 1=YES
1      FIRST CASE TO USE
1      LAST CASE TO USE
1      STEP CASE TO USE
1024   NO. OF TIME PTS. TO CALCULATE
1      FIRST EXCIT. (INPUT) TO USE
1      LAST  EXCIT. (INPUT) TO USE
1      FIRST RESPONSE NO. (OUTPUT) TO USE
30     LAST  RESPONSE NO. (OUTPUT) TO USE
1      PRINT OUT MODAL FREQS, ZETAPS, ETC? 1=YES
1      FIRST MODE TO INCLUDE IN CALCULATION
100    LAST MODE TO INCLUDE IN  CALCULATION (LARGE NO. FOR ALL)
1      HOW TO COMPUTE RESPONSE? 1=USE ALL MODES, 2=ONE MODE AT A TIME
1      OUTPUT DATA PARSING FACTOR? 1=WRITE OUT EVERY DATA PT, 2=EVERY OTHER, ETC
```

The following information appears on your computer screen when file P10B_MIMO2.COM is executed:

---

[203]Program ERAP10B also calculates general responses of a discrete-time model. Chapter 8 describes pre- and post-processors.

```
ERAP10B. SIMULATION OF DISCRETE-TIME LINEAR SYSTEMS WITH ARBITRARY
INPUTS.  USES [Z_EVALUES,BDMODAL,CDMODAL,DDMODAL] FROM TAPE79.
  SOLVES:   X(N+1) = AX(N) + BU(N)
              Y(N) = CX(N) + DU(N)
 *** ASSUMING BLOCK DIAGONAL A MATRIX ***

TAPE79 FILENAME ?  [DEFAULT FILE TYPE = .DAT]
79MIMO2.DAT

CHOOSE ONE:  (2)
 1. COMPUTE PULSE RESPONSE
 2. EXCITATION HISTORIES PROVIDED
 3. COMPUTE APPROX. IMPULSE RESPONSE (NORMALIZED PULSE RESPONSE)
          1

TAPE1 FILENAME FOR WRITING OUTPUT DATA ? [DEFAULT TYPE = .DAT]
T1TEMP.DAT

CHANGE ALL NEGATIVE (UNSTABLE) DAMPING VALUES TO 0.0? 1=YES (1)
          1

PRINT OUT Z-PLANE EIGENVALUES ? 1=YES (0
          1

WOULD YOU LIKE TO CALCULATE THE AVG. % ERROR
BETWEEN THE CALCULATED RESPONSES AND A SET OF MEASURED
RESPONSES ? 1=YES  (0)
          1

TAPE1 FILENAME CONTAINING THESE MEASURED RESPONSES ? [DEFAULT TYPE = .DAT]
T1MIMO1_SH1.DAT

STARTING RECORD NO. ON FILE
T1MIMO1_SH1.DAT
FOR READING  THE MEASURED RESPONSES ?  (1)
          1

WRITE CALCULATED AVG. % ERROR VALUES TO A FILE ? 1=YES (0)
          0

LOOPOP ........................  0
PAR(1) - PAR(5) ..... -999.0 -999.0 -999.0 -999.0 -999.0
NCASES ........................    1

FIRST CASE TO USE ?  (1)
          1

LAST CASE TO USE ?  (   1)
          1

STEP CASE TO USE [I.E., DO LOOP INCREMENT] ?  (1)
          1

CASE NO. ........................    1
```

```
 NO. OF INIT. CONDITIONS (INPUTS) ....   3
 NO. OF MEASUREMENTS (OUTPUTS) .......  30
 IORDER ..............................   8
 DT ..................................  0.0100
 NO. OF REAL EIGENVALUES .............   2
 NO. OF PAIRS OF COMPLEX EIGENVALUES .   3


NO. OF TIME POINTS TO CALCULATE ?  ( 1000)
       1024

FIRST INITIAL CONDITION NO. [INPUT NO.] TO INCLUDE IN CALCULATION ?  (1)
          1

LAST INITIAL CONDITION NO. [INPUT NO.] TO INCLUDE IN CALCULATION ?  ( 3)
          1

FIRST RESPONSE NO. [OUTPUT NO.] TO CONSTRUCT ?  (1)
          1

LAST RESPONSE NO. [OUTPUT NO.] TO CONSTRUCT ?  ( 30)
         30

PRINT OUT MODAL FREQS, ZETAPS, ETC.? 1=YES  (1)
          1
VARIABLE z_evalues READ FROM TAPE79.

Z_EVALUES :
          REAL      IMAG.      MAG.       PHSD
    1    0.5490     0.0000    0.5490     0.0000
    2   -0.3864     0.0000    0.3864   180.0000
    3    0.8040     0.5840    0.9937    35.9939
    4    0.8040    -0.5840    0.9937   -35.9939
    5    0.5822     0.8015    0.9906    54.0084
    6    0.5822    -0.8015    0.9906   -54.0084
    7   -0.2975     0.9159    0.9630   107.9965
    8   -0.2975    -0.9159    0.9630  -107.9965
VARIABLE cd_modal READ FROM TAPE79.
VARIABLE bd_modal READ FROM TAPE79.
VARIABLE dd_modal READ FROM TAPE79.
VARIABLE fd READ FROM TAPE79.
VARIABLE zetap READ FROM TAPE79.
VARIABLE zeta2p READ FROM TAPE79.
VARIABLE cmi READ FROM TAPE79.
VARIABLE msr READ FROM TAPE79.

NO. OF REAL EIGENVALUES =      2
NO. OF MODES (PAIRS OF COMPLEX EIGENVALUES) =      3 :

FIRST MODE TO INCLUDE IN THE CALCULATION ? (1)
          1

LAST MODE TO INCLUDE IN THE CALCULATION ? [ENTER LARGE NO. FOR ALL]  (    3)
        100
```

```
ONLY     3 MODES ARE AVAILABLE. THIS NUMBER WILL BE USED.

HOW SHOULD RESPONSE BE COMPUTED ? (1)
 1. USING ALL MODES SIMULTANEOUSLY
 2. USING EACH MODE INDIVIDUALLY
          1

OUTPUT DATA PARSING FACTOR ?  (1)
 1 = WRITE OUT EVERY CALCULATED DATA PT.
 2 = WRITE OUT EVERY 2ND CALCULATED DATA PT.
 ETC.
          1

 MODE        FD       ZETAP     ZETA2P      CMI      MSR
  ---        --       -----     ------      ---      ---
    1     9.998       1.007      0.993    97.09    20.41
    2    15.002       1.000      0.975    97.87    38.83
    3    29.999       1.997      1.989    98.70    89.67
NT =   100
NT =   200
NT =   300
NT =   400
NT =   500
NT =   600
NT =   700
NT =   800
NT =   900
NT =  1000
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.       1 =       0.5175
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.       2 =       0.4805
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.       3 =       0.4972
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.       4 =       0.5197
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.       5 =       0.5010
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.       6 =       0.5136
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.       7 =       0.5002
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.       8 =       0.5117
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.       9 =       0.5059
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      10 =       0.5110
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      11 =       0.5232
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      12 =       0.4946
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      13 =       0.5251
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      14 =       0.5129
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      15 =       0.4873
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      16 =       0.5170
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      17 =       0.4921
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      18 =       0.5124
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      19 =       0.5059
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      20 =       0.5037
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      21 =       0.5036
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      22 =       0.5062
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      23 =       0.5148
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      24 =       0.5103
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      25 =       0.4838
```

```
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      26 =       0.5078
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      27 =       0.5021
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      28 =       0.5067
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      29 =       0.4813
CASE NO.:       1, AVG. % ERROR FOR RESPONSE NO.      30 =       0.5037

FOR CASE NO.    1:
WROTE OUT   30 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1TEMP.DAT
NTIM =  1024
(OUTPUT DATA PARSING FACTOR =      1)
```

Program ERAP10B computes all 30 pulse response functions for Input No. 1 and writes them to file T1TEMP.DAT in Tape1 format (ref. Section 4.1). Each data record contains 1024 time samples. The calculated average error between the original PRF and the model-predicted PRF is approximately 0.5% for every response point. This error corresponds to the level of noise specified when the Tape1 data files for this test case were generated.[204]

Next, program ERAP88 constructs a temporary Tape1 file by interleaving the original data records on file T1MIMO1_SH1 with the predicted PRFs on file T1TEMP.DAT. A temporary Tape1 file is necessary to plot both data and predicted PRFs using program ERAG1. GO input file P88_MIMO2.COM is available for this purpose. Copy it from directory ERA$GO and execute it in the usual manner using GO. Here is a listing of file P88_MIMO2.COM:

```
$! P88_MIMO2.COM
$!
$ RUN ERA$EXES:ERAP88
T1MIMO1_SH1    1ST INPUT TAPE1 FILE
T1TEMP         2ND INPUT TAPE1 FILE
DATA_VS_RECON_MIMO2  OUTPUT TAPE1 FILE
0     WRITE CC FILE?  1=YES
1024 NTIM
1     START RECORD ON 1ST FILE TO COPY
1     NO. OF CONSECUTIVE RECORDS TO COPY
0     NO. OF DATA SAMPLES TO SKIP AT BEGINNING OF EACH RECORD ON 1ST FILE
1     START RECORD ON 2ND FILE TO COPY
1     NO. OF CONSECUTIVE RECORDS TO COPY
0     NO. OF DATA SAMPLES TO SKIP AT BEGINNING OF EACH RECORD ON 2ND FILE
100   NO. OF TIME TO MAKE ALTERNATING READS & WRITES?
```

The following information appears on your computer screen when file P88_MIMO2.COM is executed:

```
ERAP88. UTILITY PROGRAM TO INTERLEAVE DATA ON TWO TAPE1 FILES
```

[204] A noise level of 1% was specified which has an average value of 0.5% because the noise is uniformly distributed between 0 and 1%.

```
        (CAN BE USED TO COMBINE DATA & RECONSTRUCTION RESULTS, E.G.,
         FOR OVERLAY PLOTTING WITH ERAG1)

NAME OF 1ST TAPE1 FILE ?  [DEFAULT FILE TYPE = .DAT]
T1MIMO1_SH1.DAT

NAME OF 2ND TAPE1 FILE ?  [DEFAULT FILE TYPE = .DAT]
T1TEMP.DAT

NAME FOR OUTPUT TAPE1 FILE ?  [DEFAULT FILE TYPE = .DAT]
DATA_VS_RECON_MIMO2.DAT

WRITE COORDINATE-CODE FILE ALSO?  1=YES  (1)
          0

NTIM ?  ( 1024)
       1024

START RECORD ON 1ST TAPE1 FILE TO COPY ?  (1)
          1

NO. OF CONSECUTIVE RECORDS TO COPY FROM 1ST FILE BEFORE SWITCHING
TO 2ND FILE ?  (1)
          1

NO. OF SAMPLES TO SKIP AT THE BEGINNING OF EACH
RECORD ON 1ST TAPE1 FILE ?  (0)
          0

START RECORD ON 2ND TAPE1 FILE TO COPY ?  (1)
          1

NO. OF CONSECUTIVE RECORDS TO COPY FROM 2ND FILE BEFORE SWITCHING
BACK TO 1ST FILE ?  (1)
          1

NO. OF SAMPLES TO SKIP AT THE BEGINNING OF EACH
RECORD ON 2ND TAPE1 FILE ?  (0)
          0

NO. OF CONSECUTIVE TIMES TO MAKE THESE ALTERNATING READS & WRITES ?  (10000)
        100
WROTE REC.      1
WROTE REC.      2
WROTE REC.      3
WROTE REC.      4
WROTE REC.      5
WROTE REC.      6
WROTE REC.      7
WROTE REC.      8
WROTE REC.      9
WROTE REC.     10
WROTE REC.     11
WROTE REC.     12
```

```
WROTE REC.     13
WROTE REC.     14
WROTE REC.     15
WROTE REC.     16
WROTE REC.     17
WROTE REC.     18
WROTE REC.     19
WROTE REC.     20
WROTE REC.     21
WROTE REC.     22
WROTE REC.     23
WROTE REC.     24
WROTE REC.     25
WROTE REC.     26
WROTE REC.     27
WROTE REC.     28
WROTE REC.     29
WROTE REC.     30
WROTE REC.     31
WROTE REC.     32
WROTE REC.     33
WROTE REC.     34
WROTE REC.     35
WROTE REC.     36
WROTE REC.     37
WROTE REC.     38
WROTE REC.     39
WROTE REC.     40
WROTE REC.     41
WROTE REC.     42
WROTE REC.     43
WROTE REC.     44
WROTE REC.     45
WROTE REC.     46
WROTE REC.     47
WROTE REC.     48
WROTE REC.     49
WROTE REC.     50
WROTE REC.     51
WROTE REC.     52
WROTE REC.     53
WROTE REC.     54
WROTE REC.     55
WROTE REC.     56
WROTE REC.     57
WROTE REC.     58
WROTE REC.     59
WROTE REC.     60

END-OF-FILE ENCOUNTERED ON 1ST DATA FILE.

   60 RECORDS WRITTEN TO OUTPUT FILE
    DATA_VS_RECON_MIMO2.DAT
```

Now, plot the first 2 records of this temporary Tape1 file (DATA_VS_RECON_MIMO2.DAT) using GO input file G1T_MIMO2.COM. The first record is Measurement No. 1 (for Input 1) that was analyzed by ERA, and the second record is the corresponding predicted PRF generated from the identified [A,B,C.D] model. Execute file G1T_MIMO2.COM as follows:

```
COPY ERA$GO:G1T_MIMO2.COM []

GO G1T_MIMO2
```

Here is a listing of file G1T_MIMO2.COM:

```
$! G1T_MIMO2.COM
$!
$ RUN ERA$EXES:ERAG1
DATA_VS_RECON_MIMO2     TAPE1 FILENAME
1           FIRST RECORD TO PLOT
2           LAST RECORD TO PLOT
1           RECORD INCREMENT BETWEEN PLOTS
1           PLOT TYPE? 1=TIME, 2=FREQ, 3=BOTH
1           NO. OF PLOTS TO PLACE HORIZONTALLY ON PAGE
1           NO. OF PLOTS TO PLACE VERTICALLY ON PAGE
2           NO. OF CONSECUTIVE FUNCTIONS TO OVERLAY IN EACH PLOT
1           LINE STYLE? 1=SOLID, 2=SOLID & 3 DASHED (CYCLICALLY), 3=SOLID LINE #1.
0           INCLUDE COORDINATE CODES?  1=YES
100         SAMPLING FREQ., HZ
0           START TIME TO PLOT, SEC
0.5         FINAL TIME TO PLOT, SEC
0.01        DELTA TIME (SEC.) FOR X-AXIS MINOR TIC MARKS.  0 = NONE
0      **   LINEAR(0) OR LOG(1) SCALE FOR TIME HISTORY Y-AXIS
0,0         MIN. & MAX. VALUES FOR TIME HISTORY Y-AXIS.  0,0 = AUTOSCALE
0           DELTA AMPL. FOR Y-AXIS MINOR TIC MARKS.  0 = NONE
0           HIGHLIGHT EACH DATA PT ON TIME HISTORY?  1=YES
1           STAIRSTEP TIME HISTORY PLOT? 1=YES
7           Y AXIS LABEL FOR TIME HISTORY. 1=T1DATA,2=DISP IN IN.,3=ACCEL IN G'S
0           REMOVE DC VALUE?  1=YES
0.3         CHARACTER SIZE IN CM
1           FONT TYPE.  1=STICK
0           PRINT OUT SPECTRUM TO FILE G1_SPECTRUM.OUT?  1=YES
1           USE DEFAULT OVERALL WINDOW SIZE?  1=YES
0           MODIFY DEFAULT AXIS NUMBERS?  1=YES
```

Fig. 9-3 compares the original and predicted PRFs.[205] There is only a small difference between the 2 functions. This difference is the 1% added noise. If this test case is rerun

[205]Input and output time histories of discrete-time systems are traditionally plotted in "staircase" fashion.

using noiseless data (by setting parameter PNOISE = 0 in file RUN_MIMO1.COM), the data and predicted PRFs are identical.

You can compare the other pairs of data and predicted PRFs on file DATA_VS_RECON_MIMO2.DAT by changing line 6 of file G1T_MIMO2.COM (LAST RECORD TO PLOT) from 2 to 60.

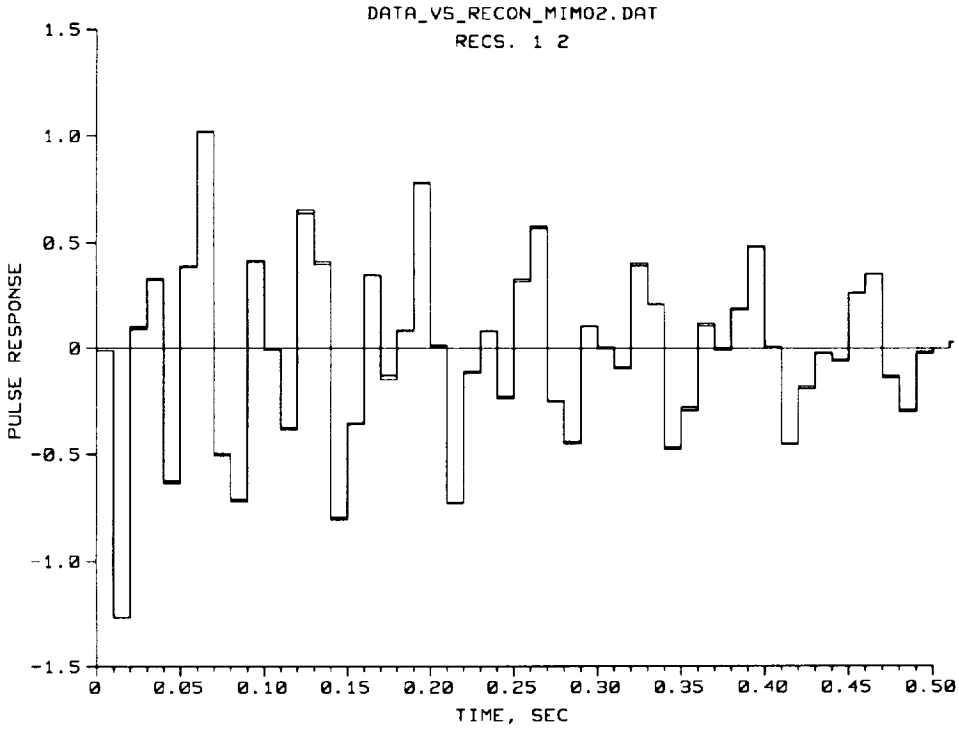


Fig. 9-3. Comparison of Data and ERAP10B-Calculated PRF for MIMO2 [G1T_MIMO2.COM]

Next, the [A,B,C,D] ERA model is transferred to MATLAB.[206] First, convert the Tape79 output file to MATLAB format using program ERAP79. Program ERAP79 converts the ASCII Tape79 file (MATRIXx format) to a binary MATLAB .MAT file.[207] GO Input file P79_MIMO2.COM is available for this purpose. Execute it in the usual manner as follows:

```
COPY ERA$GO:P79_MIMO2.COM []

GO P79_MIMO2
```

---

[206]MATLAB is often used for control design.

[207]**MATLAB binary .MAT files can be transferred to other types of computers and read by MATLAB. This is a standard feature of MATLAB.** The author typically transfers ERAP79-generated files from a VAX computer to a Macintosh with MATLAB.

Here is a listing of file P79_MIMO2.COM:

```
$! P79_MIMO2.COM
$!
$ RUN ERA$EXES:ERAP79
79MIMO2.DAT     INPUT TAPE79 FILE NAME
MIMO2.MAT       OUTPUT .MAT FILE NAME
```

The following information appears on your computer screen when P79_MIMO2.COM is executed:

```
ERAP79.  CONVERT TAPE79 FILE (ASCII MATRIXX FORMAT)
         TO BINARY MATLAB .MAT FILE

TAPE79 INPUT FILENAME ?  [DEFAULT FILE TYPE = .DAT])
79MIMO2.DAT

MATLAB OUTPUT FILENAME ?  [DEFAULT FILE TYPE = .MAT])
MIMO2.MAT

VARIABLE        ROWS     COLS
--------        ----     ----
t1_o1_i1         50        1
loopop            1        1
par              10        1
ncases            1        1
icase             1        1
dt                1        1
mtim              1        1
nreval            1        1
ncmds             1        1
ntim              1        1
sf                1        1
nst               1        1
nic               1        1
nskip             1        1
iorder            1        1
fmin              1        1
modeld            1        1
s_evalues         8        2
measid            2       30
icid              2        3
nsdrpt            3        1
ad                8        8
z_evalues         8        2
cd               30        8
bd                8        3
cd_modal         30        8
bd_modal          8        3
dd               30        3
dd_modal         30        3
```

```
fd              3       1
zetap           3       1
zeta2p          3       1
cmi             3       1
emac            3       1
mpc_w           3       1
mpc_u           3       1
prc             3       1
aratio          3       1
recip           3       1
msr             3       1

THESE VARIABLES HAVE BEEN WRITTEN INTO A BINARY MATLAB .MAT FILE NAMED:
MIMO2.MAT
```

Next, calculate pulse response functions for this test case using MATLAB (as a check of the results obtained with ERAP10B). Load file MIMO2.MAT into MATLAB and examine its contents using the 'whos' command:

```
>>load mimo2
>>whos
        Name          Size            Elements    Bytes  Density  Complex

          ad          8 by 8                64      512     Full       No
      aratio          3 by 1                 3       24     Full       No
          bd          8 by 3                24      192     Full       No
    bd_modal          8 by 3                24      192     Full       No
          cd         30 by 8               240     1920     Full       No
    cd_modal         30 by 8               240     1920     Full       No
         cmi          3 by 1                 3       24     Full       No
          dd         30 by 3                90      720     Full       No
    dd_modal         30 by 3                90      720     Full       No
          dt          1 by 1                 1        8     Full       No
        emac          3 by 1                 3       24     Full       No
          fd          3 by 1                 3       24     Full       No
        fmin          1 by 1                 1        8     Full       No
       icase          1 by 1                 1        8     Full       No
        icid          2 by 3                 6       48     Full       No
      iorder          1 by 1                 1        8     Full       No
      loopop          1 by 1                 1        8     Full       No
      measid          2 by 30               60      480     Full       No
      modeld          1 by 1                 1        8     Full       No
       mpc_u          3 by 1                 3       24     Full       No
       mpc_w          3 by 1                 3       24     Full       No
         msr          3 by 1                 3       24     Full       No
        mtim          1 by 1                 1        8     Full       No
      ncases          1 by 1                 1        8     Full       No
       ncmds          1 by 1                 1        8     Full       No
         nic          1 by 1                 1        8     Full       No
      nreval          1 by 1                 1        8     Full       No
      nsdrpt          3 by 1                 3       24     Full       No
       nskip          1 by 1                 1        8     Full       No
         nst          1 by 1                 1        8     Full       No
```

```
          ntim      1 by 1          1        8      Full      No
           par     10 by 1         10       80      Full      No
           prc      3 by 1          3       24      Full      No
         recip      3 by 1          3       24      Full      No
     s_evalues      8 by 2         16      128      Full      No
            sf      1 by 1          1        8      Full      No
      t1_o1_i1     50 by 1         50      400      Full      No
     z_evalues      8 by 2         16      128      Full      No
        zeta2p      3 by 1          3       24      Full      No
         zetap      3 by 1          3       24      Full      No

Grand total is 981 elements using 7848 bytes
```

Here are the ERA-calculated [ad,bd,cd,dd] matrices:[208]

```
>>ad

ad =

   -0.2503    0.9169   -0.0129    0.0106    0.0010   -0.0007   -0.0013    0.0000
   -0.9172   -0.3443    0.0035   -0.0053    0.0009    0.0006    0.0033    0.0026
   -0.0021    0.0355    0.4810   -0.8058    0.0159    0.0307   -0.0013    0.0044
   -0.0015    0.0076    0.8052    0.6876   -0.0121    0.0043   -0.0047    0.0054
    0.0023   -0.0018    0.0678    0.0145    0.8611   -0.5904   -0.0059   -0.0064
    0.0014    0.0005   -0.0280    0.0145    0.5890    0.7419   -0.0022   -0.0032
   -0.0031    0.0036   -0.0094    0.0051   -0.0068    0.0093   -0.3410   -0.1357
    0.0016    0.0003   -0.0033   -0.0108   -0.0228    0.0039   -0.2976    0.5039

>>bd

bd =

    2.2663    3.4740    3.5219
   -0.3879   -0.6374   -0.6701
    2.4689   -0.2527   -1.8716
   -0.8591   -0.0564    0.7649
    0.2473   -0.8356    0.7181
    1.1787   -1.5697    0.7407
    0.0141    0.0314   -0.0046
   -0.0784   -0.0984    0.2024

>>cd

cd =

   -0.4108   -0.0799   -0.1585   -0.0697    0.0389   -0.0426   -0.0086   -0.0156
   -0.7862   -0.1531   -0.3108   -0.1331    0.0791   -0.0892    0.0005    0.0285
   -1.0818   -0.2098   -0.4453   -0.1923    0.1206   -0.1339    0.0256    0.0073
   -1.2923   -0.2547   -0.5705   -0.2532    0.1465   -0.1738   -0.0586   -0.0561
   -1.3681   -0.2650   -0.6675   -0.2981    0.1777   -0.2183   -0.0052    0.0793
```

[208] [ad,bd,cd,dd] are obtained using Eq. 2-39.

```
   -1.3294   -0.2627   -0.7438   -0.3247    0.2046   -0.2637   -0.0037   -0.0625
   -1.1612   -0.2322   -0.7669   -0.3541    0.2234   -0.2928    0.0068    0.0158
   -0.8913   -0.1831   -0.7765   -0.3680    0.2524   -0.3359   -0.0362    0.0113
   -0.5373   -0.1213   -0.7544   -0.3609    0.2682   -0.3767   -0.0290    0.0492
   -0.1298   -0.0418   -0.6948   -0.3467    0.2818   -0.4077    0.0052    0.0100
    0.2854    0.0356   -0.6120   -0.3196    0.2929   -0.4394    0.0030   -0.0089
    0.6764    0.1110   -0.4963   -0.2867    0.2986   -0.4588   -0.0278   -0.0223
    1.0046    0.1765   -0.3653   -0.2358    0.3061   -0.4829   -0.0311   -0.0112
    1.2458    0.2227   -0.2119   -0.1841    0.3023   -0.4997   -0.0543    0.1198
    1.3660    0.2496   -0.0540   -0.1241    0.2901   -0.5161    0.0310   -0.0003
    1.3656    0.2514    0.1002   -0.0659    0.2881   -0.5209    0.0111    0.0254
    1.2320    0.2341    0.2577   -0.0136    0.2693   -0.5287    0.0334    0.0190
    0.9982    0.1937    0.4062    0.0520    0.2493   -0.5200   -0.0105   -0.0078
    0.6662    0.1346    0.5339    0.1025    0.2371   -0.5248    0.0523   -0.0154
    0.2700    0.0657    0.6398    0.1551    0.2176   -0.5021    0.0262   -0.0034
   -0.1493   -0.0090    0.7199    0.1929    0.1994   -0.4772    0.0061    0.0080
   -0.5537   -0.0812    0.7727    0.2196    0.1782   -0.4541   -0.0372   -0.0332
   -0.9088   -0.1469    0.7902    0.2396    0.1629   -0.4222   -0.0153   -0.0759
   -1.1784   -0.2011    0.7871    0.2389    0.1350   -0.3787   -0.0354    0.0507
   -1.3460   -0.2331    0.7451    0.2338    0.1228   -0.3340    0.0667    0.0202
   -1.3883   -0.2380    0.6703    0.2166    0.0927   -0.2921   -0.0366   -0.0366
   -1.3024   -0.2228    0.5770    0.1896    0.0811   -0.2334    0.0531    0.0635
   -1.1008   -0.1911    0.4512    0.1513    0.0672   -0.1799   -0.0433    0.0227
   -0.7904   -0.1384    0.3110    0.1055    0.0356   -0.1205   -0.0045    0.0107
   -0.4162   -0.0719    0.1573    0.0545    0.0214   -0.0602   -0.0004   -0.0223

>>dd

dd =

   -0.0120    0.0127    0.0145
   -0.0072    0.0081   -0.0256
   -0.0208    0.0034    0.0260
    0.0224   -0.0272   -0.0288
    0.0358   -0.0186    0.0045
   -0.0271   -0.0395    0.0462
   -0.0012    0.0036    0.0336
   -0.0328    0.0139   -0.0094
   -0.0001    0.0002   -0.0106
   -0.0142   -0.0071   -0.0100
   -0.0040    0.0077    0.0146
   -0.0082   -0.0092   -0.0036
    0.0100   -0.0157   -0.0294
   -0.0173    0.0104    0.0245
   -0.0152   -0.0214   -0.0350
   -0.0063    0.0236   -0.0180
    0.0132   -0.0377    0.0143
   -0.0012    0.0379    0.0288
    0.0119    0.0006   -0.0262
   -0.0009   -0.0074    0.0068
   -0.0194    0.0027   -0.0128
   -0.0147   -0.0047    0.0244
   -0.0131    0.0060   -0.0455
    0.0038    0.0137    0.0383
```

```
 0.0135   -0.0296   -0.0091
-0.0176   -0.0027    0.0455
-0.0344   -0.0179    0.0158
 0.0172   -0.0001    0.0252
-0.0090    0.0232   -0.0045
-0.0057   -0.0033   -0.0010
```

Calculate the predicted pulse response function (PRF) for Input 1 and Output 1 using the MATLAB dimpulse command. Plot this PRF and the corresponding data function (t1_o1_i1) as follows:[209]

```
>>y=dimpulse(ad,bd,cd,dd,1,50);
>>[xx1,yy1]=stairs(y(:,1));[xx2,yy2]=stairs(t1_o1_i1);
>>plot(xx1,yy1,'k');hold on;plot(xx2,yy2,'k')
>>plot([0 50],[0 0],'k');hold off
>>title('Pulse Response Using [ad,bd,cd,dd] vs. Data')
>>xlabel('No. of Samples'),ylabel('Amplitude')
```

Fig. 9-4 shows the resulting plot. The small difference between the two functions is the 1% noise added to the data. These results are identical to those shown in Fig. 9-3 obtained using ERA postprocessor ERAP10B.

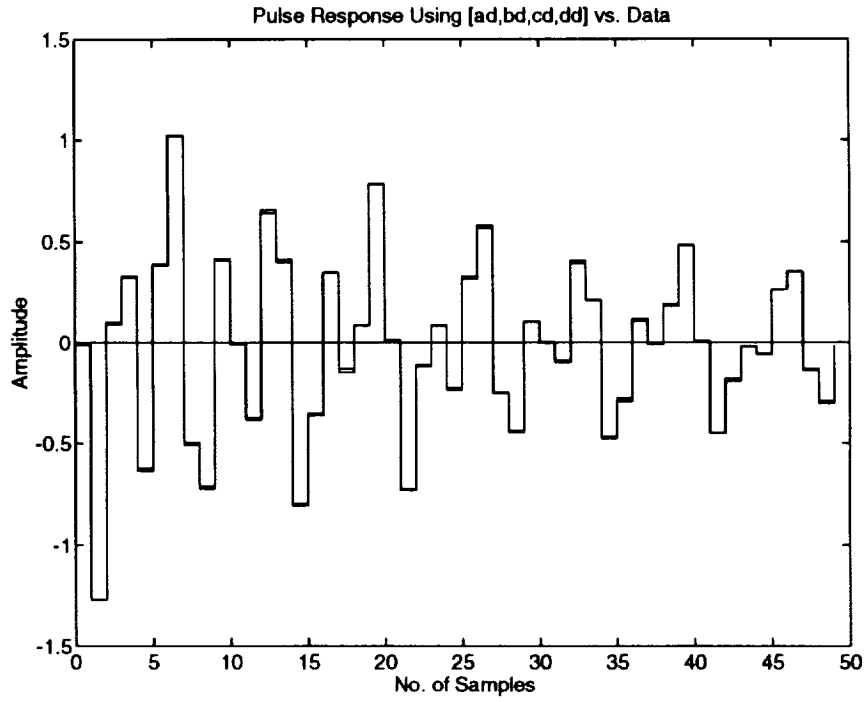


Fig. 9-4. Comparison of Data and MATLAB-Calculated PRF for MIMO2 Using [ad,bd,cd,dd]

[209]MATLAB variable t1_oX_iY contains the Tape1 data record for Output X - Input Y.

In practice, the modal form of [ad,bd,cd,dd] may be preferable so that particular modes can be deemphasized (or deleted) in the model during the control design process.[210] Modal [bd,cd,dd] matrices are stored on Tape79 as variables [bd_modal,cd_modal,dd_modal]. **The modal ad matrix, however, is not stored on Tape79 because it is very sparse. It is easily calculated, however, from variable z_evalues containing the z-domain eigenvalues.** The M-file named 'build_ad_modal' is available for this purpose.[211] Here is a listing of this file:

```
% BUILD_AD_MODAL. Build ad_modal matrix from Tape79 results:
%  ns        = total no. of states
%  nreval    = no. of identified real eigenvalues
%  z_evalues = identified z-domain eigenvalues
%
% R. Pappa  6-30-92
%
fprintf('BUILD_AD_MODAL. Build discrete-time modal A matrix (ad_modal) from
z_evalues.\n\n')
fprintf('Total no. of states (ns) = %g\n',ns)
fprintf(' consisting of:\n')
fprintf('%g real eigenvalues (nreval)\n',nreval)
fprintf('%g complex-conjugate pairs of eigenvalues ((ns-nreval)/2)\n\n', (ns-nreva
%
ad_modal = diag(z_evalues(:,1));
for i=nreval+1:2:ns-1,ad_modal(i,i+1)=z_evalues(i,2);end
for i=nreval+2:2:ns,  ad_modal(i,i-1)=z_evalues(i,2);end
```

Calculate matrix ad_modal by simply typing 'build_ad_modal' (after M-file BUILD_AD_MODAL.M is available). The following information appears on your computer screen when build_ad_modal is executed:

```
>> build_ad_modal
BUILD_AD_MODAL. Build discrete-time modal A matrix (ad_modal) from z_evalues.

Total no. of states (iorder) = 8
 consisting of:
2 real eigenvalues (nreval)
3 complex-conjugate pairs of eigenvalues ((iorder-nreval)/2)
```

[210] The modal form of [ad,bd,cd,dd] is obtained using Eq. 2-41.

[211] All MATLAB files discussed in this User's Guide are stored in directory ERA$MATLAB. They are listed in Appendix L.

Here are the [ad_modal,bd_modal,cd_modal,dd_modal] matrices:

```
>>ad_modal

ad_modal =

    0.5490         0         0         0         0         0         0         0
         0   -0.3864         0         0         0         0         0         0
         0         0    0.8040    0.5840         0         0         0         0
         0         0   -0.5840    0.8040         0         0         0         0
         0         0         0         0    0.5822    0.8015         0         0
         0         0         0         0   -0.8015    0.5822         0         0
         0         0         0         0         0         0   -0.2975    0.9159
         0         0         0         0         0         0   -0.9159   -0.2975

>>bd_modal

bd_modal =

   -0.0736   -0.1468    0.2585
   -0.0096    0.0002   -0.0056
   -1.2278    1.6916   -0.8127
    1.2843   -1.7630    0.8595
    1.6965   -0.1729   -1.4435
    3.0287   -0.3108   -2.5584
   -1.4587   -2.2128   -2.2416
   -2.9208   -4.4329   -4.4672

>>cd_modal

cd_modal =

   -0.0133    0.0150   -0.0084   -0.0391   -0.1052   -0.0464    0.0435    0.2909
    0.0297   -0.0059   -0.0162   -0.0814   -0.2039   -0.0933    0.0834    0.5568
    0.0059   -0.0217   -0.0272   -0.1213   -0.2930   -0.1344    0.1157    0.7659
   -0.0433    0.0793   -0.0301   -0.1555   -0.3779   -0.1686    0.1360    0.9161
    0.0834   -0.0139   -0.0337   -0.1949   -0.4412   -0.1978    0.1485    0.9690
   -0.0560    0.0295   -0.0395   -0.2289   -0.4882   -0.2282    0.1427    0.9430
    0.0204   -0.0061   -0.0430   -0.2543   -0.5101   -0.2279    0.1250    0.8246
    0.0234    0.0347   -0.0525   -0.2887   -0.5182   -0.2320    0.0963    0.6348
    0.0605    0.0142   -0.0543   -0.3184   -0.5014   -0.2304    0.0563    0.3861
    0.0170   -0.0079   -0.0598   -0.3394   -0.4650   -0.2136    0.0152    0.0978
   -0.0009   -0.0018   -0.0646   -0.3602   -0.4111   -0.1918   -0.0296   -0.1953
   -0.0095    0.0296   -0.0703   -0.3717   -0.3393   -0.1550   -0.0708   -0.4718
    0.0019    0.0274   -0.0764   -0.3858   -0.2519   -0.1203   -0.1045   -0.7044
    0.1344    0.0066   -0.0759   -0.3952   -0.1522   -0.0721   -0.1317   -0.8751
    0.0020   -0.0370   -0.0733   -0.3977   -0.0491   -0.0261   -0.1441   -0.9617
    0.0296   -0.0265   -0.0784   -0.3973    0.0518    0.0202   -0.1458   -0.9624
    0.0186   -0.0453   -0.0717   -0.3958    0.1523    0.0735   -0.1298   -0.8705
   -0.0027    0.0058   -0.0683   -0.3824    0.2531    0.1165   -0.1062   -0.7068
   -0.0210   -0.0501   -0.0651   -0.3799    0.3377    0.1561   -0.0722   -0.4740
   -0.0066   -0.0275   -0.0623   -0.3587    0.4112    0.1866   -0.0297   -0.1960
    0.0063   -0.0102   -0.0597   -0.3372    0.4656    0.2122    0.0148    0.0987
```

```
   -0.0290    0.0457   -0.0541   -0.3163    0.5019    0.2299    0.0578    0.3830
   -0.0755    0.0402   -0.0525   -0.2907    0.5166    0.2328    0.0948    0.6331
    0.0518    0.0205   -0.0418   -0.2593    0.5136    0.2392    0.1201    0.8239
    0.0060   -0.0658   -0.0419   -0.2270    0.4868    0.2250    0.1380    0.9420
   -0.0345    0.0506   -0.0286   -0.1951    0.4410    0.2021    0.1457    0.9720
    0.0511   -0.0663   -0.0280   -0.1570    0.3797    0.1742    0.1381    0.9117
    0.0260    0.0375   -0.0258   -0.1216    0.2982    0.1348    0.1154    0.7715
    0.0091    0.0036   -0.0113   -0.0794    0.2060    0.0936    0.0823    0.5542
   -0.0231    0.0088   -0.0086   -0.0397    0.1043    0.0464    0.0442    0.2917

>>dd_modal

dd_modal =

   -0.0120    0.0127    0.0145
   -0.0072    0.0081   -0.0256
   -0.0208    0.0034    0.0260
    0.0224   -0.0272   -0.0288
    0.0358   -0.0186    0.0045
   -0.0271   -0.0395    0.0462
   -0.0012    0.0036    0.0336
   -0.0328    0.0139   -0.0094
   -0.0001    0.0002   -0.0106
   -0.0142   -0.0071   -0.0100
   -0.0040    0.0077    0.0146
   -0.0082   -0.0092   -0.0036
    0.0100   -0.0157   -0.0294
   -0.0173    0.0104    0.0245
   -0.0152   -0.0214   -0.0350
   -0.0063    0.0236   -0.0180
    0.0132   -0.0377    0.0143
   -0.0012    0.0379    0.0288
    0.0119    0.0006   -0.0262
   -0.0009   -0.0074    0.0068
   -0.0194    0.0027   -0.0128
   -0.0147   -0.0047    0.0244
   -0.0131    0.0060   -0.0455
    0.0038    0.0137    0.0383
    0.0135   -0.0296   -0.0091
   -0.0176   -0.0027    0.0455
   -0.0344   -0.0179    0.0158
    0.0172   -0.0001    0.0252
   -0.0090    0.0232   -0.0045
   -0.0057   -0.0033   -0.0010
```

The pulse response function for Output 1 - Input 1 is once again calculated using 'dimpulse' and compared with the corresponding Tape1 data as follows:

```
>>y=dimpulse(ad_modal,bd_modal,cd_modal,dd_modal,1,50);
>>[xx1,yy1]=stairs(y(:,1));[xx2,yy2]=stairs(t1_o1_i1);
>>plot(xx1,yy1,'k');hold on;plot(xx2,yy2,'k')
```

```
>>plot([0 50],[0 0],'k');hold off
>>title('Pulse Response Using [ad_modal,bd_modal,cd_modal,dd_modal] vs. Data')
>>xlabel('No. of Samples'),ylabel('Amplitude')
```

Fig. 9-5 shows resulting plot. The MATLAB-calculated PRF is once again identical to the PRF calculated using ERA postprocessor ERAP10B (Fig. 9-3). It is also identical to the MATLAB-calculated PRF obtained using the non-modal ERA discrete model, [ad,bd,cd,dd] (Fig. 9-4).

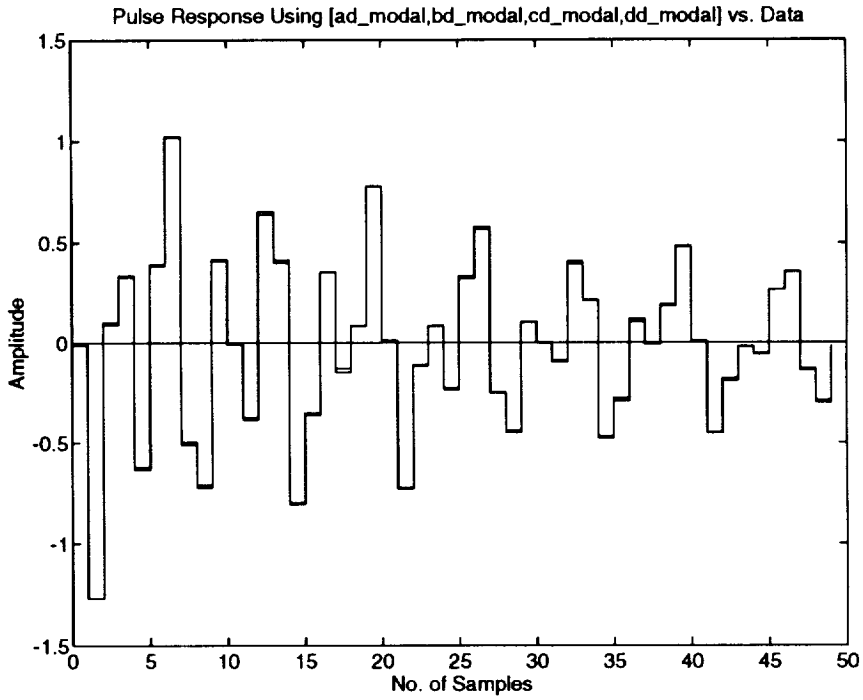


Fig. 9-5. Comparison of Data and MATLAB-Calculated PRF for MIMO2 Using [ad_modal,bd_modal,cd_modal,dd_modal]

10.0 OTHER INTERESTING EXAMPLES

Directory [ERA.OTHER_EXAMPLES] (logical name = ERA$OEXS) contains several example problems which illustrate interesting aspects of ERA. These problems are executed as VMS command procedures named EX001.COM, EX002.COM, etc. For example, Problem #1 is executed by copying file EX001.COM into your working directory and running it as follows:

```
COPY ERA$OEXS:EX001.COM []

@EX001
```

The following example problems are available:

```
EX001. ILLUSTRATE 1-MODE, NTIM=4 CAPABILITY.
EX002. ILLUSTRATE NUMERICAL STABILITY W/1-MODE, NCH=NRH=500 ANALYSIS.
EX003. ILLUSTRATE IDENTIFICATION OF REAL EIGENVALUES.
EX004. ILLUSTRATE I.D. OF ALMOST-REPEATED EIGENVALUES
       (UNIQUE I.D. OF BOTH MODE SHAPES).
EX005. ILLUSTRATE I.D. OF REPEATED EIGENVALUES
       (NON-UNIQUE I.D. OF MODE SHAPES).
EX006. ILLUSTRATE DIFFICULTY TO I.D. ALMOST-REPEATED EIGENVALUES
       WITH SINGLE-INPUT (SINGLE-REFERENCE) ANALYSIS.
EX007. ILLUSTRATE CORRECT I.D. OF ALIASED DATA USING ISTRIP > 1.
EX008. ILLUSTRATE INABILITY TO I.D. MONOPHASE MODE AT
       NYQUIST FREQ/2 = 25 HZ IF N2 = 2 (OR N3 = 2).
EX009. SAME AS EX008 EXCEPT WITH 1 DEGREE OF ADDED RANDOM PHASE ANGLE
       (TO GENERATE NON-MONOPHASE EIGENVECTORS).
EX010. SAME AS EX008, WITH 25.0 HZ MODE MOVED TO 25.01 HZ.
EX011. ILLUSTRATE NUMERICAL STABILITY WITH SINGULAR HANKEL MATRIX
       DUE TO 2 IDENTICAL INPUTS (DATA SETS)
EX012. SHOW ACCURATE I.D. OF 2 VERY CLOSELY SPACED MODES
       USING LESS THAN 1 CYCLE OF DATA OF EACH.
EX013. SHOW VARIATION OF EMAC RESULTS VS. N2LAST AND N3LAST.
EX014. TEST CASE SISO1 WITH MINIMUM HANKEL MATRIX SIZE (6 X 6).
EX015. SHOW THAT ALL EMACS = 100% WHEN N2LAST = N2, N3LAST = N3,
       NCH = NRH, AND NO SINGULAR VALUES ARE TRUNCATED.
EX016. ILLUSTRATE I.D. OF A VERY-LOW-FREQUENCY MODE AS A REAL
       EIGENVALUE.
EX017. COMPARE ZETA AND ZETA2 USING MONTE CARLO ANALYSIS OF
       NOISY DATA (50 CASES).
```

10.1 Example Problem EX001

This example demonstrates the accurate identification of the frequency, damping, amplitude, and phase (4 unknowns) of a noise-free, damped sinusoid **using only 4 data**

points. With single-input, single-output data, the minimum number of data points necessary for ERA identification of N modes is 4N (using a square Hankel matrix of size 2N x 2N).

Program SISO generates 4 data points of a damped sinusoid with the following parameters:[212]

```
Frequency:   30 Hz
Damping:     1.0 %
Amplitude:   1.0
Phase:       90 degrees
```

These parameters are defined in file EX001.COM and can be easily modified by the user. Here is a listing of file EX001.COM:

```
$! EX001.COM   ILLUSTRATE 1-MODE, NTIM=4 CAPABILITY.
$!
$! CONSTRUCT TAPE1 FILE USING SISO PROGRAM
$!
$ SISO
T1EX1.DAT   TAPE1 FILE TO CONSTRUCT
4        NTIM (NO. OF TIME POINTS TO GENERATE)
100      SAMPLING FREQUENCY
30       FREQUENCY (HZ) OF MODE 1
1        DAMPING FACTOR (%) OF MODE 1
1        INITIAL AMPLITUDE OF MODE 1
90       INITIAL PHASE (DEGREES) OF MODE 1
N        MODE MODES ?  Y OR  N
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX1.ERA []
$ @ERA EX1
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX1.ERA:

```
$!  EX1.ERA:  EXAMPLE #1
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
```

[212]Program SISO calculates the free-response time history using Eq. 9-1.

```
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX1
$!
$ INPUT1:=EX1
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=2/
S/MRH=/MRH=2/
S/MIC=/MIC=1/
S/MST=/MST=1/
S/MTIM=/MTIM=4/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=100
 MIDOPT=1,IORDTU=2
 N2LAST=1,N3LAST=1,NOFATL(44)=1,NOFATL(45)=1
 MSTO50=1,MSPP50=0
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!             [ALWAYS USE EXACTLY 5 LINES]
$!
ILLUSTRATE 1-MODE, NTIM=4 CAPABILITY
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX1:  EXAMPLE #1
```

The ERA analysis required approximately 1 second of CPU time on the author's VAXstation 3100 computer.

The identification results are highlighted in bold type near the end of the Tape50 output file (file 50EX1.LIS) shown below. **ERA identifies all 4 unknown parameters (frequency, damping, amplitude, phase) exactly.** The results are as follows:

```
Identified Frequency:  30.000 Hz
Identified Damping:    1.000 %
Identified Amplitude:  1.0000
Identified Phase:      90.0 degrees
```

Similar performance should occur for other selections of the 4 unknown parameters.

Note that 2 fatal errors (nos. 44 and 45) are bypassed by including NOFATL commands in Field 4 of the User Input file, ref. Chapter 6. These fatal errors occur because N2LAST = N2 = 1 and N3LAST = N3 = 1 in order to use the minimum number of data points in the analysis (NTIM = 4). N2LAST = N2 and N3LAST = N3 cause EMAC to be ineffective (ref. Sections 2.6.2 and 10.15). By default, N2LAST = N3LAST = 10.

File 50EX1.LIS

```
* * * ERA -- VERSION 931216 * * *

ILLUSTRATE 1-MODE, NTIM=4 CAPABILITY
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX1:  EXAMPLE #1

TAPE1 FILE NAMES:
----------------
   1. []T1EX1.DAT

-------------------------------------------------------------------------------------------------------------------
*  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * *

* * * FATAL ERROR NO. 44 IN ERA * * *

DO NOT SET N2LAST EQUAL TO N1.
(IF NRH <= NCH AND NO SINGULAR VALUES ARE TRUNCATED, ALL OUTPUT EMACS WILL BE 100%.)

*  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * *
-------------------------------------------------------------------------------------------------------------------

* NOFATL( 44) = 1.  FATAL ERROR IS IGNORED *

-------------------------------------------------------------------------------------------------------------------
*  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * *

* * * FATAL ERROR NO. 45 IN ERA * * *

DO NOT SET N3LAST EQUAL TO N1.
(IF NCH <= NRH AND NO SINGULAR VALUES ARE TRUNCATED, ALL INPUT EMACS WILL BE 100%.)

*  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * *
-------------------------------------------------------------------------------------------------------------------

* NOFATL( 45) = 1.  FATAL ERROR IS IGNORED *

ANALYSIS PARAMETERS:                                                                                  DEFAULT
--------------------                                                                                   VALUE
                 (MAX)                                                                                -------
 NCH .......   2 (    2)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)              MCH
 NRH .......   2 (    2)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)              MRH
 NIC .......   1 (    1)  - NO. OF INITIAL CONDITIONS (INPUTS)                                         MIC
 NST .......   1 (    1)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                 MST
*NTIM ......   4 (    4)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)   -

 SF ........  100.000     - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                               -
*WINDOW ....    0.030     - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                   -
 FMIN ......    0.000     - FMIN OF DATA (FOR "ZOOMED" DATA)                                         0.0
```

```
 FR1FIR ....  -999.000     - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                                -
 FR2FIR ....  -999.000     - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                                -
 IORFIR ....  50           - ORDER OF BANDPASS FIR FILTER                                                                        50

 NSFRST ....   1           - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                                       1
 NSFLAG() ..                - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]               ALL 1
          1
*NSTBOT ....   1           - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                                NST

 NGENTH ....   0           - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)          0
*NSTDTA ....   1           - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                                         -

 N1 ........   1           - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                                      1
 N2 ........   1           - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                                          1
 N3 ........   1           - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                                          1
 N2LAST ....   1           - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                                  10
 N3LAST ....   1           - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                                  10

 NSKIP .....   0           - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                              0
 ISTRIP ....   1           - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                              1
 ICAS85 ....   1           - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                                       1
 DATABW ....  -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1         -

 MODELC ....   0           - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79          0
 MODELD ....   0           - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79          0
 NOAD79 ....   0           - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)              0

*RNKTL0 ....  1.69E-07     - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)                  SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....   2           - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION (*IORDER TO USE*)                                 -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  0.00E+00     - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                                        RNKTL0
 2. MXFLAG .   0           - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                             0
 3. POFVAR . 101.0000      - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                                    99.999
 4. MXORDR .   2           - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                              0.75 * MIN(NRH,NCH)

 NUMRNK ....   0           -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BYPASSING CRITERIA 1-4 ABOVE            0

 MIDOPT ....   1           - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]                         0

 ITAPE(50) .   1           - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                                     1
 ITAPE(51) .   0           - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                                         0
 ITAPE(55) .   0           - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                             0
 ITAPE(79) .   0           - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                                   0
  MXALL ....   0           -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                                     0
  MXHANK ...   0           -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                                  0
  MXPDQT ...   0           -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                                      0
  MXMTM ....   0           -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT                    0
  MXMOMC ...   0           -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                                   0
  MXDATA ...   0           -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                                    0
   MXDNTM ..-999           -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79              MTIM
   MXDNSF ..   1           -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                                1
   MXDNSL ..   1           -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                              NST
   MXDNIF ..   1           -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                                1
   MXDNIL ..   1           -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                              NIC
 ITAPE(80) .   0           - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT   0
  IRUNAV ...   0           - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80                   0
 ITAPE(85) .   1           - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85              1
 ITAPE(88) .   0           - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                                 0
 ITYDTA ....   3           - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                               3
 MSSCAL ....   2           - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES              2
 IREFTU ....   0           - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)          0
 T55CMI ....     1.0       - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                           1.0
 T88CMI ....     1.0       - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                           1.0

 MSTO50 ....   1           - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                            0
 MSPP50 ....   0           - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)                      1

 LOOPOP ....   0           - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                         0
  PAR(1) ... -999.00       -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                             -
  PAR(2) ... -999.00       -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                             -
  PAR(3) ... -999.00       -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                             -
  PAR(4) ... -999.00       -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                             -
  PAR(5) ... -999.00       -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                             -
*NCASES ....   1           - NO. OF CONSECUTIVE CASES TO RUN                                                                     1

 IPREMC ....   0           - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                            0
 IPRHRS ....   0           - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH     0
 IPRPDQ ....   0           - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                                     0
 IPRABC ....   0           - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                                 0
 IPREVS ....   0           - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                                     0
 IPRDTA ....   0           - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                                0
 IPRPAR ....   0           - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                                0
 MSRTOT ....   0           - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                                     0

 IOMAC .....   0           - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1                     0
 ------------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ------------------------------------------------------------------
```

```
EX1:  EXAMPLE #1

CASE NO.   1:
-----------

D(1) =   1.25828E+00

                                                
```

```
START DATE/TIME:  17-MAR-1994 14:48
  END DATE/TIME:  17-MAR-1994 14:48
```

10.2 Example Problem EX002

This example demonstrates the numerical stability of the ERA method with very large model sizes. Model sizes several times larger than the theoretical minimum are often used in practice because of uncertainty in the number of modes, and because accuracy is generally improved by the principle of least-squares.

This problem uses single-input, single-output (SISO) data with 1 mode and an ERA Hankel matrix size of 500 x 500 (250 assumed modes). Program SISO generates the free-response time history with the following parameters:[213]

```
Frequency:   10 Hz
Damping:     1.0 %
Amplitude:   1.0
Phase:       90 degrees
```

These parameters are defined in file EX002.COM and can be easily modified by the user. Here is a listing of file EX002.COM:

```
$! EX002.  ILLUSTRATE NUMERICAL STABILITY OF 1-MODE,
$!         NCH=NRH=500 (250 ASSUMED MODES) ANALYSIS.
$!
$! CONSTRUCT TAPE1 FILE USING SISO PROGRAM
$!
$ SISO
T1EX2.DAT   TAPE1 FILE TO CONSTRUCT
2048     NTIM (NO. OF TIME POINTS TO GENERATE)
100      SAMPLING FREQUENCY
10       FREQUENCY (HZ) OF MODE 1
1        DAMPING FACTOR (%) OF MODE 1
1        INITIAL AMPLITUDE OF MODE 1
90       INITIAL PHASE (DEGREES) OF MODE 1
N        MODE MODES ?  Y OR  N
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX2.ERA []
$ @ERA EX2
$!
$ EXIT
```

[213]Program SISO calculates the free-response time history using Eq. 9-1.

Here is a listing of the ERA User Input file for this problem, EX2.ERA:

```
$!  EX2.ERA:  EXAMPLE #2
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX2
$!
$ INPUT1:=EX2
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=500/
S/MRH=/MRH=500/
S/MIC=/MIC=1/
S/MST=/MST=1/
S/MTIM=/MTIM=2048/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=100
 MIDOPT=1,NUMRNK=1
 MSTO50=1,MSPP50=0
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!             [ALWAYS USE EXACTLY 5 LINES]
$!
ILLUSTRATE NUM. STABILITY OF 1-MODE, NCH=NRH=500 ANALYSIS
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX2:  EXAMPLE #2
```

The ERA analysis required 18 minutes and 22 seconds of CPU time on the author's VAXstation 3100 computer.

The identification results are highlighted in bold type near the end of the Tape50 output file (file 50EX2.LIS) shown below. **ERA identifies all 4 unknown parameters (frequency, damping, amplitude, phase) exactly. Also, singular-value**

truncation occurs <u>automatically</u> at Order = 2, corresponding to 1 mode. The results are as follows:

```
Identified Frequency:  10.000 Hz
Identified Damping:    1.000 %
Identified Amplitude:  1.0000
Identified Phase:      90.0 degrees
```

File 50EX2.LIS

```
* * * ERA -- VERSION 931216 * * *


ILLUSTRATE NUM. STABILITY OF 1-MODE, NCH=NRH=500 ANALYSIS
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX2:  EXAMPLE #2


TAPE1 FILE NAMES:
----------------
   1. []T1EX2.DAT

ANALYSIS PARAMETERS:                                                                                                    DEFAULT
------------------                                                                                                       VALUE
                (MAX)                                                                                                   -------
 NCH ....... 500 (  500)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                                 MCH
 NRH ....... 500 (  500)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                                 MRH
 NIC .......   1 (    1)  - NO. OF INITIAL CONDITIONS (INPUTS)                                                            MIC
 NST .......   1 (    1)  - NO. OF RESPONSE STATIONS (OUTPUTS)   [ = NGENTH + NSTDTA]                                     MST
*NTIM ......1018 ( 2048)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)                  -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                                 -
*WINDOW ....    10.170    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                                      -
 FMIN ......     0.000    - FMIN OF DATA (FOR "ZOOMED" DATA)                                                            0.0

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                        -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                        -
 IORFIR ....  50          - ORDER OF BANDPASS FIR FILTER                                                                 50

 NSFRST ....   1          - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                               1
 NSFLAG() ..               - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]        ALL 1
           1
*NSTBOT ....   1          - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                         NST

 NGENTH ....   0          - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)   0
*NSTDTA ....   1          - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                                  -

 N1 ........   1          - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                               1
 N2 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                                   1
 N3 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                                   1
 N2LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                            10
 N3LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                            10

 NSKIP .....   0          - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                       0
 ISTRIP ....   1          - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                       1
 ICAS85 ....   1          - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                                1
 DATABW ....  -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1  -

 MODELC ....   0          - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79   0
 MODELD ....   0          - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79   0
 NOAD79 ....   0          - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)      0

*RNKTL0 ....  4.22E-05    - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)              SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....-999           - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")                          -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  4.22E-05    - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                                   RNKTL0
 2. MXFLAG .   0          - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                       0
 3. POFVAR . 101.0000     - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                                99.999
 4. MXORDR . 500          - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                    0.75 * MIN(NRH,NCH)

 NUMRNK ....   1          -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BYPASSING CRITERIA 1-4 ABOVE     0

 MIDOPT ....   1          - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]                  0

 ITAPE(50) .   1          - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                              1
```

```
 ITAPE(51) .    0          - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                                    0
 ITAPE(55) .    0          - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                        0
 ITAPE(79) .    0          - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                              0
  MXALL ....    0          -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                                0
  MXHANK ...    0          -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                              0
  MXPDQT ...    0          -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                                  0
  MXMTM ....    0          -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT               0
  MXMOMC ...    0          -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                               0
  MXDATA ...    0          -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                                0
   MXDNTM ..-999           -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79          MTIM
   MXDNSF ..   1           -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                              1
   MXDNSL ..   1           -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                            NST
   MXDNIF ..   1           -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                              1
   MXDNIL ..   1           -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                            NIC
 ITAPE(80) .    0          - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...    0          - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80              0
 ITAPE(85) .    1          - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85         1
 ITAPE(88) .    0          - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                            0
 ITYDTA ....    3          - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                          3
 MSSCAL ....    2          - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES         2
 IREFTU ....    0          - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)     0
 T55CMI ....      1.0      - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                      1.0
 T88CMI ....      1.0      - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                      1.0

 MSTO50 ....    1          - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                       0
 MSPP50 ....    0          - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)                 1

 LOOPOP ....    0          - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                    0
  PAR(1) ... -999.00        -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                        -
  PAR(2) ... -999.00        -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                        -
  PAR(3) ... -999.00        -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                        -
  PAR(4) ... -999.00        -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                        -
  PAR(5) ... -999.00        -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                        -
*NCASES ....   1            - NO. OF CONSECUTIVE CASES TO RUN                                                              1

 IPREMC ....    0          - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                       0
 IPRHRS ....    0          - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH  0
 IPRPDQ ....    0          - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                                0
 IPRABC ....    0          - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                            0
 IPREVS ....    0          - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                                0
 IPRDTA ....    0          - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                           0
 IPRPAR ....    0          - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                           0
 MSRTOT ....    0          - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                                0

 IOMAC .....    0          - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1                0
 ---------------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ---------------------------------------------------------------------


EX2:  EXAMPLE #2

CASE NO.   1:
------------

D(1) =   4.03054E+01

                                                                                                                  CUMULATIVE
                                                                                                                    % OF
SINGULAR VALUES, D():                                                                          D(N)/D(1)  D(N)/D(N+1) VARIANCE   N

  1 **************************************************************************************************          1.00E+00      1.017   50.86030   1
  2 **************************************************************************************************          9.83E-01* 6.135E+05  100.00000   2

  3 XXXXXXXXXXXXXXXXXXXXXXXXX                                                                                   1.60E-06      1.007  100.00000   3
  4 +++++++++++++++++++++++++                                                                                    1.59E-06      1.270  100.00000   4
  5 ++++++++++++++++++++++++                                                                                     1.25E-06      1.015  100.00000   5
  6 ++++++++++++++++++++++++                                                                                     1.23E-06      1.038  100.00000   6
  7 ++++++++++++++++++++++++                                                                                     1.19E-06      1.004  100.00000   7
  8 ++++++++++++++++++++++++                                                                                     1.19E-06      1.125  100.00000   8
  9 ++++++++++++++++++++++                                                                                       1.05E-06      1.087  100.00000   9
 10 ++++++++++++++++++++++++                                                                                     9.69E-07      1.005  100.00000  10
 11 ++++++++++++++++++++++++                                                                                     9.64E-07      1.004  100.00000  11
 12 ++++++++++++++++++++++++                                                                                     9.61E-07      1.080  100.00000  12
 13 ++++++++++++++++++++++                                                                                       8.90E-07      1.004  100.00000  13
 14 ++++++++++++++++++++++                                                                                       8.86E-07      1.005  100.00000  14
 15 ++++++++++++++++++++++                                                                                       8.82E-07      1.012  100.00000  15
 16 ++++++++++++++++++++++                                                                                       8.72E-07      1.016  100.00000  16
 17 ++++++++++++++++++++++                                                                                       8.58E-07      1.003  100.00000  17
 18 ++++++++++++++++++++++                                                                                       8.56E-07      1.024  100.00000  18
 19 ++++++++++++++++++++++                                                                                       8.36E-07      1.001  100.00000  19
 20 ++++++++++++++++++++++                                                                                       8.35E-07      1.039  100.00000  20
 21 ++++++++++++++++++++++                                                                                       8.04E-07      1.027  100.00000  21
 22 ++++++++++++++++++++++                                                                                       7.82E-07      1.026  100.00000  22
 23 ++++++++++++++++++++                                                                                         7.63E-07      1.008  100.00000  23
 24 ++++++++++++++++++++                                                                                         7.57E-07      1.002  100.00000  24
 25 ++++++++++++++++++++                                                                                         7.55E-07      1.055  100.00000  25
 26 ++++++++++++++++++++                                                                                         7.16E-07      1.016  100.00000  26
 27 ++++++++++++++++++++                                                                                         7.05E-07      1.042  100.00000  27
 28 ++++++++++++++++++++                                                                                         6.76E-07      1.004  100.00000  28
 29 ++++++++++++++++++++                                                                                         6.74E-07      1.001  100.00000  29
 30 ++++++++++++++++++++                                                                                         6.73E-07      1.010  100.00000  30
```

```
  .
  .
  .
161 ++++++++++++++                                                  1.92E-07     1.002  100.00000 161
162 ++++++++++++++                                                  1.92E-07     1.002  100.00000 162
163 ++++++++++++++                                                  1.91E-07     1.013  100.00000 163
164 ++++++++++++++                                                  1.89E-07     1.001  100.00000 164
165 ++++++++++++++                                                  1.89E-07     1.003  100.00000 165
166 ++++++++++++++                                                  1.88E-07     1.000  100.00000 166
167 ++++++++++++++                                                  1.88E-07     1.000  100.00000 167
168 ++++++++++++++                                                  1.88E-07     1.014  100.00000 168
169 ++++++++++++++                                                  1.85E-07     1.001  100.00000 169
170 ++++++++++++++                                                  1.85E-07     1.006  100.00000 170
171 ++++++++++++++                                                  1.84E-07     1.001  100.00000 171
172 ++++++++++++++                                                  1.84E-07     1.010  100.00000 172
173 ++++++++++++++                                                  1.82E-07     1.013  100.00000 173
174 +++++++++++++                                                   1.80E-07     1.002  100.00000 174
175 +++++++++++++                                                   1.80E-07     1.003  100.00000 175
176 +++++++++++++                                                   1.79E-07     1.016  100.00000 176
177 +++++++++++++                                                   1.76E-07     1.009  100.00000 177
178 +++++++++++++                                                   1.75E-07     1.002  100.00000 178
179 +++++++++++++                                                   1.74E-07     1.010  100.00000 179
180 +++++++++++++                                                   1.73E-07     1.001  100.00000 180
181 +++++++++++++                                                   1.73E-07     1.002  100.00000 181
182 +++++++++++++                                                   1.72E-07     1.013  100.00000 182
183 +++++++++++++                                                   1.70E-07     1.017  100.00000 183
184 +++++++++++++                                                   1.67E-07            100.00000 184
185 +                                                               0.00E+00            100.00000 185
186 +                                                               0.00E+00            100.00000 186
187 +                                                               0.00E+00            100.00000 187
188 +                                                               0.00E+00            100.00000 188
189 +                                                               0.00E+00            100.00000 189
190 +                                                               0.00E+00            100.00000 190
191 +                                                               0.00E+00            100.00000 191
192 +                                                               0.00E+00            100.00000 192
193 +                                                               0.00E+00            100.00000 193
194 +                                                               0.00E+00            100.00000 194
195 +                                                               0.00E+00            100.00000 195
196 +                                                               0.00E+00            100.00000 196
197 +                                                               0.00E+00            100.00000 197
198 +                                                               0.00E+00            100.00000 198
199 +                                                               0.00E+00            100.00000 199
200 +                                                               0.00E+00            100.00000 200
  .
  .
  .
491 +                                                               0.00E+00            100.00000 491
492 +                                                               0.00E+00            100.00000 492
493 +                                                               0.00E+00            100.00000 493
494 +                                                               0.00E+00            100.00000 494
495 +                                                               0.00E+00            100.00000 495
496 +                                                               0.00E+00            100.00000 496
497 +                                                               0.00E+00            100.00000 497
498 +                                                               0.00E+00            100.00000 498
499 +                                                               0.00E+00            100.00000 499
500 +                                                               0.00E+00            100.00000 500

                                    NUMERICAL RANK =    2
                                    --------------------

                  *  SINGULAR VALUE TRUNCATION OCCURRED AT ORDER =    2  *


INPUT (REFERENCE) COORDINATE CODES:
----------------------------------
  IC NO.     COORDINATE CODE       MEAS. NO.
    1              1X+                 1


* NOTE: FMIN =     0.0000, SF =    100.0000, N1 =  1, ISTRIP =  1.

  THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN      0.0000 &     50.0000 HZ


IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):
------------------------------------------------------------------

    E.V.  FREQUENCY,  DAMPING                          AVG.     EMACS >= 80%                                          RECIP-
     NO.    HERTZ    FACTOR, % (ZETA2,%)     CMI,%     EMAC,%    INPUT  OUTPUT     MPC-W   MPC-U   PRC    ARATIO   PROCITY  MSR,%
                                                                 (   1) (   1)
-------------------------------------------------------------------------------------------------------------------------------
```

```
  1   1    10.000**    1.000    ( 1.000)  :   99.90**   99.90  :      1      1  : -999.00 -999.00  -999  :  0.002  :-999.0  101.0


IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):
-------------------------------------------------------------------

    E.V.  FREQUENCY,  DAMPING                          AVG.     EMACS >= 80%                                                    RECIP-
     NO.     HERTZ    FACTOR, % (ZETA2,%)     CMI,%    EMAC,%   INPUT  OUTPUT     MPC-W    MPC-U   PRC    ARATIO   PROCITY  MSR,%
                                                                 (  1) (  1)
-------------------------------------------------------------------------------------------------------------------------------
  1   1    10.000**    1.000    ( 1.000)  :   99.90**   99.90  :      1      1  : -999.00 -999.00  -999  :  0.002  :-999.0  101.0


IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):
-------------------------------------------------

    E.V.  FREQUENCY,  DAMPING                          AVG.     EMACS >= 80%                                                    RECIP-
     NO.     HERTZ    FACTOR, % (ZETA2,%)     CMI,%    EMAC,%   INPUT  OUTPUT     MPC-W    MPC-U   PRC    ARATIO   PROCITY  MSR,%
                                                                 (  1) (  1)
-------------------------------------------------------------------------------------------------------------------------------
  1   1    10.000**    1.000    ( 1.000)  :   99.90**   99.90  :      1      1  : -999.00 -999.00  -999  :  0.002  :-999.0  101.0


                                          ------------------------------------------------
                                          EIGENVALUE NO.  1       FREQUENCY =   10.000 HZ
                                          ------------------------------------------------

EIGENVALUE  FREQUENCY,   DAMPING    MEAS.   MEAS.   NORMALIZED      ---------------- INITIAL PHYSICAL AMPLITUDES ----------------
   NO.        HERTZ     FACTOR, %   POS.     NO.    MODE SHAPE       IC # 1     1X+

    1       10.000**     1.000      1X+       1    100.00   90.0    1.0000E+00   90.0

                        NORMALIZED MODAL PARTICIPATION FACTOR(S):      100.00     0.0

VAX EXECUTION STATISTICS:
-------------------------

COMPUTER NODENAME AND TYPE:  SDBHR,  VAXstation 3100-M76/GPX

ELAPSED:    0 00:19:46.96  CPU: 0:18:21.55  BUFIO: 292  DIRIO: 1539  FAULTS: 13738

START DATE/TIME:  17-MAR-1994 15:52
  END DATE/TIME:  17-MAR-1994 16:12
```

10.3 Example Problem EX003

This example demonstrates the identification of real eigenvalues.[214] Single-input, single-output (SISO) data with 1 mode and 3 real eigenvalues (order = 5) is analyzed using a Hankel matrix size of 20 x 20. Program SISO generates the free-response time history with the following parameters:[215]

Mode 1

Frequency: 10 Hz
Damping: 1.0 %
Amplitude: 1.0
Phase: 90 degrees

Real Eigenvalue 1

Time Constant: 0.05 sec
Amplitude: 0.7

Real Eigenvalue 2

Time Constant: 0.03 sec

[214]Structural modes correspond to complex-conjugate pairs of eigenvalues. Real eigenvalues model distortion effects or actual system dynamics in control applications.

[215]Program SISO calculates the free-response time history using Eq. 9-1.

```
Amplitude:  -1.0

Real Eigenvalue  3
Time Constant: 0.02 sec
Amplitude:  1.5
```

These parameters are defined in file EX003.COM and can be easily modified by the user. Here is a listing of file EX003.COM:

```
$! EX003. ILLUSTRATE IDENTIFICATION OF REAL EIGENVALUES.
$!
$! CONSTRUCT TAPE1 FILE USING SISO PROGRAM
$!
$ SISO
T1EX3.DAT   TAPE1 FILE TO CONSTRUCT
1024     NTIM (NO. OF TIME POINTS TO GENERATE)
100      SAMPLING FREQUENCY
10       FREQUENCY (HZ) OF MODE 1  (0.0 FOR REAL EIGENVALUE)
1        DAMPING FACTOR (%) OF MODE 1
1        INITIAL AMPLITUDE OF MODE 1
90       INITIAL PHASE (DEGREES) OF MODE 1
Y        MODE MODES ?  Y OR N
0        FREQUENCY (HZ) OF NEXT MODE  (0.0 FOR REAL EIGENVALUE)
0.05     TIME CONSTANT (SEC) OF REAL EV #1
0.7      INITIAL AMPLITUDE OF REAL EV #1
Y        MODE MODES ?  Y OR N
0        FREQUENCY (HZ) OF NEXT MODE  (0.0 FOR REAL EIGENVALUE)
0.03     TIME CONSTANT (SEC) OF REAL EV #2
-1.0     INITIAL AMPLITUDE OF REAL EV #2
Y        MODE MODES ?  Y OR N
0        FREQUENCY (HZ) OF NEXT MODE  (0.0 FOR REAL EIGENVALUE)
0.02     TIME CONSTANT (SEC) OF REAL EV #3
1.5      INITIAL AMPLITUDE OF REAL EV #3
N        MODE MODES ?  Y OR N
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX3.ERA []
$ @ERA EX3
$!
$ EXIT
```

Output file Tape50 does <u>not</u> normally contain information for real eigenvalues. Include parameter IPRREV = 1 in Field 4 of the User Input file to see this information. IPRREV is an acronym for "Print Real Eigenvalues." Here is a listing of the ERA User Input file for this problem, EX3.ERA:

```
$!  EX3.ERA:  EXAMPLE #3
$!
```

```
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX3
$!
$ INPUT1:=EX3
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=20/
S/MRH=/MRH=20/
S/MIC=/MIC=1/
S/MST=/MST=1/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=100
 MIDOPT=1,NUMRNK=1,IPRREV=1
 MSTO50=1,MSPP50=0
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!            [ALWAYS USE EXACTLY 5 LINES]
$!
ILLUSTRATE IDENTIFICATION OF REAL EIGENVALUES.
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX3:  EXAMPLE #3
```

The ERA analysis required approximately 1 second of CPU time on the author's VAXstation 3100 computer.

The identification results are highlighted in bold type near the end of the Tape50 output file (file 50EX3.LIS) shown below. **All unknown parameters (frequency, damping, amplitude, and phase for the structural mode, and time constant and amplitude for the real eigenvalues) are well identified. Also, singular-value**

truncation occurred automatically at Order = 5, corresponding to 1 mode and 3 real eigenvalues.

Table 10-1 compares the true and identified parameters.

	True Value	Identified Value
Mode 1		
Frequency, Hz	10.0	10.000
Damping, %	1.0	1.000
Amplitude	1.0	1.0000
Phase, deg.	90.0	90.0
Real Eigenvalue 1		
Time Constant, sec	0.05	0.05000
Amplitude	0.7	0.7003
Real Eigenvalue 2		
Time Constant, sec	0.03	0.03001
Amplitude	-1.0	-0.9995
Real Eigenvalue 3		
Time Constant, sec	0.02	0.02000
Amplitude	1.5	1.499

Table 10-1. ERA Results for Example Problem EX003

File 50EX3.LIS

```
* * * ERA -- VERSION 931216 * * *

ILLUSTRATE IDENTIFICATION OF REAL EIGENVALUES.
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX3:  EXAMPLE #3

TAPE1 FILE NAMES:
----------------
   1. []T1EX3.DAT

ANALYSIS PARAMETERS:                                                                                    DEFAULT
-------------------                                                                                      VALUE
                  (MAX)                                                                                  -------
 NCH .......  20 (   20)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                 MCH
 NRH .......  20 (   20)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                 MRH
 NIC .......   1 (    1)  - NO. OF INITIAL CONDITIONS (INPUTS)                                            MIC
 NST .......   1 (    1)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                     MST
*NTIM ......  58 ( 1024)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)    -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                    -
*WINDOW ....     0.570    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                        -
 FMIN ......     0.000    - FMIN OF DATA (FOR "ZOOMED" DATA)                                              0.0

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                           -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                           -
```

```
 IORFIR ....  50          - ORDER OF BANDPASS FIR FILTER                                                                  50

 NSFRST ....   1          - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                                 1
 NSFLAG() ..              - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]       ALL 1
        1
*NSTBOT ....   1          - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                          NST

 NGENTH ....   0          - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)    0
*NSTDTA ....   1          - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                                  -

 N1 ........   1          - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                               1
 N2 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                                   1
 N3 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                                   1
 N2LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                            10
 N3LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                            10

 NSKIP .....   0          - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                        0
 ISTRIP ....   1          - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                        1
 ICAS85 ....   1          - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                                 1
 DATABW ....  -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1   -

 MODELC ....   0          - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79    0
 MODELD ....   0          - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79    0
 NOAD79 ....   0          - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)       0

*RNKTL0 ....  1.69E-06    - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)          SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....-999          - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION (*IORDER TO USE*)                           -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  1.69E-06    - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                                  RNKTL0
 2. MXFLAG .   0          - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                       0
 3. POFVAR . 101.0000     - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                               99.999
 4. MXORDR .  20          - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                        0.75 * MIN(NRH,NCH)

 NUMRNK ....   1          -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BYPASSING CRITERIA 1-4 ABOVE      0

 MIDOPT ....   1          - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]                  0

 ITAPE(50) .   1          - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                               1
 ITAPE(51) .   0          - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                                   0
 ITAPE(55) .   0          - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                       0
 ITAPE(79) .   0          - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                             0
  MXALL ....   0          -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                               0
  MXHANK ...   0          -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                            0
  MXPDQT ...   0          -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                                0
  MXMTM ....   0          -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT              0
  MXMOMC ...   0          -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                             0
  MXDATA ...   0          -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                              0
   MXDNTM ..-999          -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79        MTIM
   MXDNSF ..   1          -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                            1
   MXDNSL ..   1          -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                          NST
   MXDNIF ..   1          -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                            1
   MXDNIL ..   1          -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                          NIC
 ITAPE(80) .   0          - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...   0          - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80             0
 ITAPE(85) .   1          - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85        1
 ITAPE(88) .   0          - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                           0
 ITYDTA ....   3          - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                         3
 MSSCAL ....   2          - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES        2
 IREFTU ....   0          - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)    0
 T55CMI ....     1.0      - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                     1.0
 T88CMI ....     1.0      - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                     1.0

 MSTO50 ....   1          - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                      0
 MSPP50 ....   0          - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)                1

 LOOPOP ....   0          - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                   0
  PAR(1) ... -999.00      -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                       -
  PAR(2) ... -999.00      -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                       -
  PAR(3) ... -999.00      -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                       -
  PAR(4) ... -999.00      -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                       -
  PAR(5) ... -999.00      -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                       -
*NCASES ....   1          - NO. OF CONSECUTIVE CASES TO RUN                                                               1

 IPREMC ....   0          - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                      0
 IPRHRS ....   0          - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH  0
 IPRPDQ ....   0          - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                               0
 IPRABC ....   0          - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                           0
 IPREVS ....   0          - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                               0
 IPRREV ....   1          - IF IPRREV=1, PRINT TIME CONSTANTS & INITIAL AMPS OF REAL EIGENVALUES ON TAPE50                 0
 IPRDTA ....   0          - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                          0
 IPRPAR ....   0          - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                          0
 MSRTOT ....   0          - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                               0

 IOMAC .....   0          - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1               0
 ---------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ---------------------------------------------------------------
```

EX3: EXAMPLE #3

CASE NO. 1:

D(1) = 9.48236E+00

SINGULAR VALUES, D():

		D(N)/D(1)	D(N)/D(N+1)	CUMULATIVE % OF VARIANCE	N
1	**********	1.00E+00	1.105	53.81463	1
2	**********	9.05E-01	4.602	97.90047	2
3	**********	1.97E-01	10.904	99.98244	3
4	**********	1.80E-02	23.126	99.99996	4
5	**********	7.80E-04*	2771.386	100.00000	5
6	XXXXXXXXXXXXXXXXX	2.81E-07	1.163	100.00000	6
7	+++++++++++++++++	2.42E-07	1.150	100.00000	7
8	++++++++++++++++	2.10E-07	1.248	100.00000	8
9	+++++++++++++++	1.69E-07		100.00000	9
10	+	0.00E+00		100.00000	10
11	+	0.00E+00		100.00000	11
12	+	0.00E+00		100.00000	12
13	+	0.00E+00		100.00000	13
14	+	0.00E+00		100.00000	14
15	+	0.00E+00		100.00000	15
16	+	0.00E+00		100.00000	16
17	+	0.00E+00		100.00000	17
18	+	0.00E+00		100.00000	18
19	+	0.00E+00		100.00000	19
20	+	0.00E+00		100.00000	20

NUMERICAL RANK = 5

* SINGULAR VALUE TRUNCATION OCCURRED AT ORDER = 5 *

TIME CONSTANTS OF REAL EIGENVALUES:

REAL EV NO. 1, TIME CONSTANT = 5.000E-02 SECS
REAL EV NO. 2, TIME CONSTANT = 3.001E-02 SECS
REAL EV NO. 3, TIME CONSTANT = 2.000E-02 SECS

INITIAL AMPLITUDES OF REAL EIGENVALUES:

REAL EV NO. 1, OUTPUT NO. 1, INPUT NO. 1, AMPLITUDE = 7.003E-01
REAL EV NO. 2, OUTPUT NO. 1, INPUT NO. 1, AMPLITUDE = -9.995E-01
REAL EV NO. 3, OUTPUT NO. 1, INPUT NO. 1, AMPLITUDE = 1.499E+00

INPUT (REFERENCE) COORDINATE CODES:

IC NO.	COORDINATE CODE	MEAS. NO.
1	1X+	1

* NOTE: FMIN = 0.0000, SF = 100.0000, N1 = 1, ISTRIP = 1.

THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN 0.0000 & 50.0000 HZ

IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	EMACS >= 80% OUTPUT (1)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	10.000**	1.000	(1.000)	99.99**	99.99	1	1	-999.00	-999.00	-999	0.703	-999.0	96.8

IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	EMACS >= 80% OUTPUT (1)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	10.000**	1.000	(1.000)	99.99**	99.99	1	1	-999.00	-999.00	-999	0.703	-999.0	96.8

```
IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):
-------------------------------------------------

    E.V.  FREQUENCY,  DAMPING                          AVG.     EMACS >= 80%                                                  RECIP-
     NO.    HERTZ     FACTOR, % (ZETA2,%)      CMI,%    EMAC,%    INPUT  OUTPUT     MPC-W   MPC-U   PRC    ARATIO   PROCITY  MSR,%
                                                                  (   1) (   1)
-------------------------------------------------------------------------------------------------------------------------------------
  1   1    10.000**    1.000    ( 1.000)  :   99.99**   99.99  :      1      1  : -999.00 -999.00  -999  :  0.703  :-999.0   96.8


                                                  ---------------------------------------------
                                                  EIGENVALUE NO.  1       FREQUENCY =   10.000 HZ
                                                  ---------------------------------------------

EIGENVALUE  FREQUENCY,   DAMPING    MEAS.   MEAS.   NORMALIZED      --------------- INITIAL PHYSICAL AMPLITUDES ---------------
    NO.       HERTZ     FACTOR, %    POS.    NO.    MODE SHAPE        IC # 1      1X+

     1       10.000**     1.000      1X+      1   100.00   90.0    1.0000E+00   90.0

                       NORMALIZED MODAL PARTICIPATION FACTOR(S):       100.00    0.0

VAX EXECUTION STATISTICS:
-------------------------

COMPUTER NODENAME AND TYPE:  SDBHR,  VAXstation 3100-M76/GPX

ELAPSED:    0 00:00:04.31  CPU: 0:00:01.15  BUFIO: 53  DIRIO: 79  FAULTS: 838

START DATE/TIME:  18-MAR-1994 15:38
  END DATE/TIME:  18-MAR-1994 15:38
```

10.4 Example Problem EX004

Example Problems EX004, EX005, and EX006 illustrate various aspects of the identification of repeated modes (eigenvalues). Repeated modes of multiplicity m are m modes with identical frequency and damping. ERA typically uses data for multiple input (and output) locations simultaneously in the analysis to efficiently identify closely spaced modes.

Identification of repeated modes of multiplicity m requires at least m linearly independent inputs and at least m linearly independent outputs. Linear independence of m inputs corresponds mathematically to matrix Z having rank m, as follows:

$$Rank(Z) = Rank\begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1m''} \\ Z_{21} & Z_{22} & \cdots & Z_{2m''} \\ \vdots & \vdots & \ddots & \vdots \\ Z_{m'1} & Z_{m'2} & \cdots & Z_{m'm''} \end{bmatrix} = m \qquad (10\text{-}1)$$

where $m' \geq m$, $m'' \geq m$, and Z_{ij} = shape of repeated mode i at input location j. Note that Z_{ij}, in general, is a complex number. A similar rank condition holds for linear independence of m outputs.

Repeated eigenvalues of multiplicity m must have m linearly independent eigenvectors to be identified. However, the m eigenvectors are nonunique (ref. Section 10.5); that is, any linear combination of the eigenvectors is also an eigenvector (Ref. 21). When there is a slight difference in the eigenvalues, the corresponding eigenvectors are unique.[216]

This example problem (EX004) illustrates the unique identification of almost-repeated modes (15.0 and 15.001 Hz). Program MIMO generates free-response time histories for 2 inputs and 30 outputs with the following parameters:[217]

Mode 1		**Mode 2**	
Frequency:	10 Hz	Frequency:	15 Hz
Damping:	1.0 %	Damping:	1.0 %
Amplitude:	1.0	Amplitude:	1.0

Mode 3		**Mode 4**	
Frequency:	15.001 Hz	Frequency:	20 Hz
Damping:	1.0 %	Damping:	1.0 %
Amplitude:	1.0	Amplitude:	1.0

These parameters are defined in file EX004.COM and can be easily modified by the user. Here is a listing of file EX004.COM:

```
$! EX004. ILLUSTRATE I.D. OF ALMOST-REPEATED EIGENVALUES
$!         (UNIQUE I.D. OF BOTH MODE SHAPES)
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO PROGRAM
$!
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
$!
$ MIMO
ERAEX4.OUT
 &MIMOIN
 T1NAMS='T1EX4_IC1','T1EX4_IC2'
 PNOISE = 0
 NIC = 2, INLOC = 7,25
 NST = 30
 NTIM = 1024
 SF = 100.
 NMODES = 4
 FREQ = 10.0, 15.0, 15.001, 20.0
 ZETAP  = 4*1.0
 AMODES = 4*1.0
 NPTMSR = 43
 &END
```

[216]Experimentally, identical mode shapes may be obtained for distinct eigenvalues due to an inadequate number or distribution of response sensors.

[217]Program MIMO calculates the free-response histories using Eq. 9-2.

```
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX4.ERA []
$ @ERA EX4
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX4.ERA:

```
$!  EX4.ERA:  EXAMPLE #4
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX4
$!
$ INPUT1:=EX4_IC1
$ INPUT2:=EX4_IC2
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=30/
S/MRH=/MRH=150/
S/MIC=/MIC=2/
S/MST=/MST=30/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                       OF AVAILABLE PARAMETERS]
$!
 SF=100
 NUMRNK=1,ITAPES=88
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!             [ALWAYS USE EXACTLY 5 LINES]
$!
ILLUSTRATE IDENTIFICATION OF ALMOST REPEATED EIGENVALUE (15 & 15.001 HZ)
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX4:  EXAMPLE #4
```

The ERA analysis required approximately 4 seconds of CPU time on the author's VAXstation 3100 computer.

The results appear at the end of the Tape50 output file listed below (partial file). **ERA identifies all modal parameters exactly. Also, singular-value truncation occurs automatically at Order = 8, corresponding to 4 modes.**

Fig. 10-1 shows the corresponding mode shapes plotted using GO Input file G5_EX4.COM.[218] **All 4 mode shapes are identified exactly.**

File 50EX4.LIS (partial)

```
                                                                                                                  CUMULATIVE
                                                                                                                    % OF
SINGULAR VALUES, D():                                                                                D(N)/D(1)   D(N)/D(N+1) VARIANCE   N

  1 ************************************************************************************************  1.00E+00      1.053   26.12813   1
  2 ************************************************************************************************  9.50E-01      1.240   49.70471   2
  3 ************************************************************************************************  7.66E-01      1.043   65.03779   3
  4 ************************************************************************************************  7.34E-01      1.297   79.12504   4
  5 ************************************************************************************************  5.66E-01      1.244   87.50161   5
  6 ************************************************************************************************  4.55E-01      1.100   92.91187   6
  7 ************************************************************************************************  4.14E-01      1.308   97.38516   7
  8 ************************************************************************************************  3.16E-01* 6.263E+05  100.00000   8

  9 XXXXXXXXXXXXXXXXXXX                                                                                5.05E-07      1.073  100.00000   9
 10 +++++++++++++++++++                                                                                4.71E-07      1.835  100.00000  10
 11 +++++++++++++++++                                                                                  2.56E-07             100.00000  11
 12 +                                                                                                  0.00E+00             100.00000  12
 13 +                                                                                                  0.00E+00             100.00000  13
 14 +                                                                                                  0.00E+00             100.00000  14
 15 +                                                                                                  0.00E+00             100.00000  15
 16 +                                                                                                  0.00E+00             100.00000  16
 17 +                                                                                                  0.00E+00             100.00000  17
 18 +                                                                                                  0.00E+00             100.00000  18
 19 +                                                                                                  0.00E+00             100.00000  19
 20 +                                                                                                  0.00E+00             100.00000  20
 21 +                                                                                                  0.00E+00             100.00000  21
 22 +                                                                                                  0.00E+00             100.00000  22
 23 +                                                                                                  0.00E+00             100.00000  23
 24 +                                                                                                  0.00E+00             100.00000  24
 25 +                                                                                                  0.00E+00             100.00000  25
 26 +                                                                                                  0.00E+00             100.00000  26
 27 +                                                                                                  0.00E+00             100.00000  27
 28 +                                                                                                  0.00E+00             100.00000  28
 29 +                                                                                                  0.00E+00             100.00000  29
 30 +                                                                                                  0.00E+00             100.00000  30

                                        NUMERICAL RANK =    8
                                        --------------------

                    *  SINGULAR VALUE TRUNCATION OCCURRED AT ORDER =    8  *

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):
-------------------------------------------------

    E.V.  FREQUENCY,  DAMPING                          AVG.     EMACS >= 80%                                                  RECIP-
     NO.    HERTZ    FACTOR, % (ZETA2,%)     CMI,%     EMAC,%    INPUT  OUTPUT     MPC-W   MPC-U   PRC    ARATIO   PROCITY  MSR,%
                                                                  (   2) (  30)
-------------------------------------------------------------------------------------------------------------------------------
  1   1    10.000**    1.000   ( 1.000)  :  100.00**  100.00  :     2     30  :  100.00  100.00  1000  :  0.798  : 100.0   41.1
-------------------------------------------------------------------------------------------------------------------------------
  2   2    15.000**    1.000   ( 1.000)  :  100.00**  100.00  :     2     30  :  100.00  100.00  1000  :  0.712  : 100.0   61.9
```

[218]Chapter 8 explains the operation of pre- and post-processors using GO.

3	3	15.001**	1.000	(1.000)	:	100.00**	100.00	:	2	30	:	100.00	99.98	998	:	0.712	:	100.0	58.7
4	4	20.000**	1.000	(1.000)	:	100.00**	100.00	:	2	30	:	100.00	100.00	1000	:	0.636	:	100.0	32.2

```
VAX EXECUTION STATISTICS:
-------------------------

COMPUTER NODENAME AND TYPE:  SDBHR,  VAXstation 3100-M76/GPX

ELAPSED:    0 00:00:07.76  CPU: 0:00:03.49  BUFIO: 64  DIRIO: 108  FAULTS: 981

START DATE/TIME:  21-MAR-1994 13:18
  END DATE/TIME:  21-MAR-1994 13:18
```

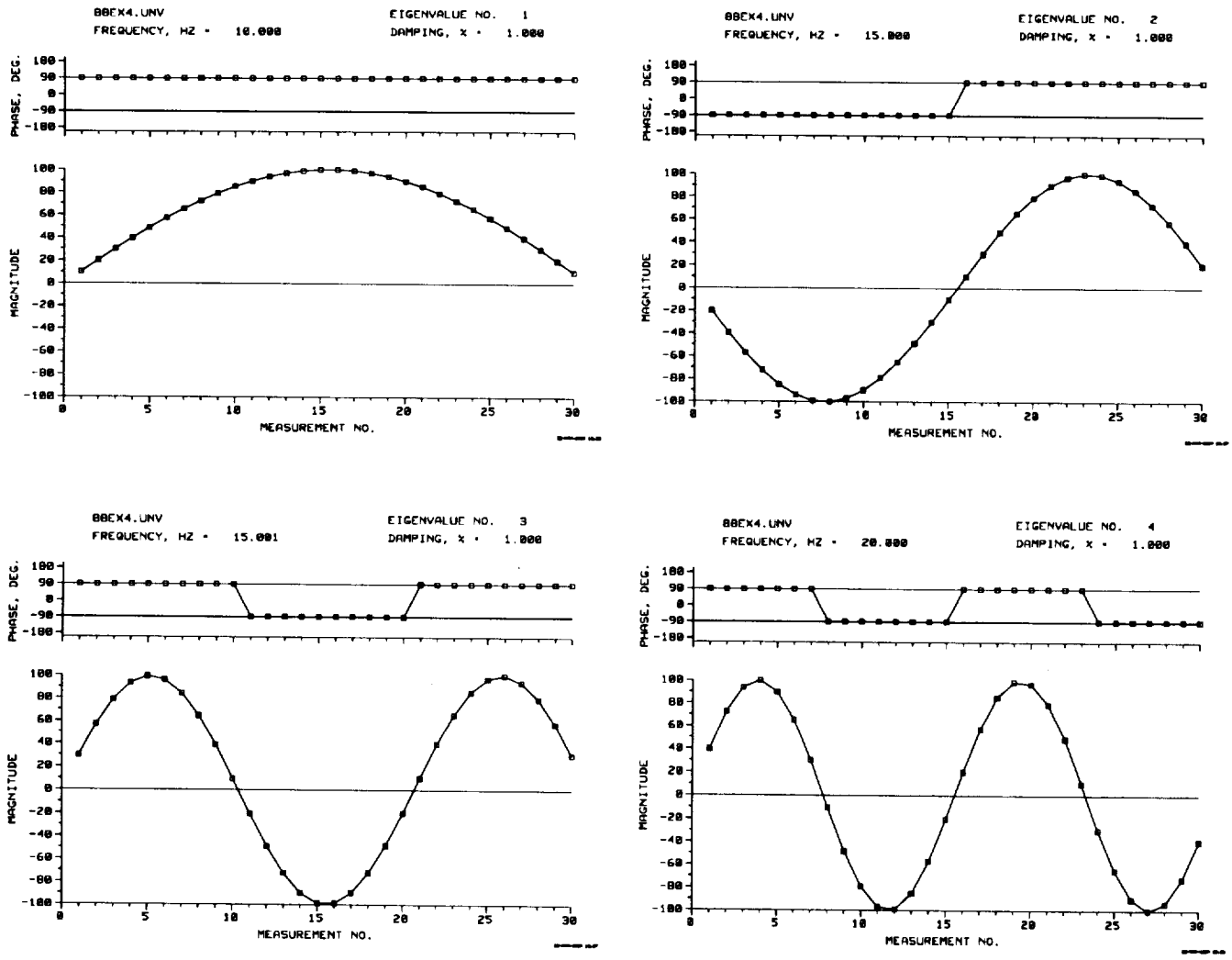


Fig. 10-1. Mode Shape Results for Example Problem EX004 (= True Mode Shapes) [G5_EX4.COM][219]

[219]The name in brackets in figure titles is the name of the GO Input file which generates the figure. Sample GO Input files are stored in directory ERA$GO.

10.5 Example Problem EX005

This example demonstrates identification of a repeated eigenvalue of multiplicity 2. For repeated eigenvalues (having identical frequency and damping), the corresponding mode shapes (eigenvectors) are not unique, ref. discussion at beginning of Section 10.4. Linear combinations of the eigenvectors are also valid eigenvectors (Ref. 21).[220]

Program MIMO generates free-response time histories for 2 inputs and 30 outputs with the following parameters:[221]

Mode 1		**Mode 2**	
Frequency:	10 Hz	Frequency:	15 Hz
Damping:	1.0 %	Damping:	1.0 %
Amplitude:	1.0	Amplitude:	1.0

Mode 3		**Mode 4**	
Frequency:	15 Hz	Frequency:	20 Hz
Damping:	1.0 %	Damping:	1.0 %
Amplitude:	1.0	Amplitude:	1.0

These parameters are defined in file EX005.COM and can be easily modified by the user. Here is a listing of file EX005.COM:

```
$! EX005. ILLUSTRATE I.D. OF REPEATED EIGENVALUES
$!        (NON-UNIQUE I.D. OF MODE SHAPES)
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO PROGRAM
$!
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
$!
$ MIMO
ERAEX5.OUT
 &MIMOIN
 T1NAMS='T1EX5_IC1','T1EX5_IC2'
 PNOISE = 0
 NIC = 2, INLOC = 7,25
 NST = 30
 NTIM = 1024
 SF = 100.
 NMODES = 4
 FREQ = 10.0, 15.0, 15.0, 20.0
 ZETAP  = 4*1.0
 AMODES = 4*1.0
 NPTMSR = 43
 &END
$!
```

[220]The linear dependence is quantified using MAC, ref. Table 10-2.

[221]Program MIMO calculates the free-response histories using Eq. 9-2.

```
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX5.ERA []
$ @ERA EX5
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX5.ERA:

```
$!  EX5.ERA:  EXAMPLE #5
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX5
$!
$ INPUT1:=EX5_IC1
$ INPUT2:=EX5_IC2
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=30/
S/MRH=/MRH=150/
S/MIC=/MIC=2/
S/MST=/MST=30/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=100
 NUMRNK=1,ITAPES=88
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!            [ALWAYS USE EXACTLY 5 LINES]
$!
ILLUSTRATE IDENTIFICATION OF A REPEATED EIGENVALUE (AT 15 HZ)
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX5:  EXAMPLE #5
```

The ERA analysis required approximately 4 seconds of CPU time on the author's VAXstation 3100 computer.

The results appear at the end of the Tape50 output file listed below (partial file). **ERA identifies all frequency and damping values exactly. Also, singular-value truncation occurs automatically at Order = 8, corresponding to 4 modes.**

Fig. 10-2 shows the corresponding mode shapes plotted using GO Input file G5_EX5.COM. **Mode shapes 1 and 4 are identified exactly. Mode shapes 2 and 3 (for the repeated mode at 15 Hz), however, are linear combinations of the 2 original shapes (shown in Fig. 10-1). These results in Fig. 10-2 are valid mode shapes (eigenvectors) for this repeated mode.** The linear relationship of identified and true modes is quantified in Table 10-2 using the Modal Assurance Criterion (MAC).[222] Identified mode shape 2 (EX005) correlates 39% with original mode 2 (EX004) and 61% with original mode 3. Identified mode shape 3 correlates 70% with original mode 2 and 30% with original mode 3. In both cases, the sum of the modal contributions equals 100%.

Note that the identified phase angles of modes 2 and 3 (Fig. 10-2) are significantly different from the classical ± 90° normal-mode characteristic. In practice, this behavior clearly signifies identification uncertainty. The Modal Phase Collinearity (and CMI) values drop accordingly.

File 50EX5.LIS (partial)

SINGULAR VALUES, D():	D(N)/D(1)	D(N)/D(N+1)	CUMULATIVE % OF VARIANCE	N
1 **********	1.00E+00	1.053	26.12849	1
2 **********	9.50E-01	1.240	49.70831	2
3 **********	7.66E-01	1.043	65.04057	3
4 **********	7.34E-01	1.297	79.12768	4
5 **********	5.66E-01	1.244	87.50293	5
6 **********	4.55E-01	1.100	92.91274	6
7 **********	4.14E-01	1.308	97.38522	7
8 **********	3.16E-01*	5.468E+05	100.00000	8
9 XXXXXXXXXXXXXXXXXXXX	5.79E-07	1.142	100.00000	9
10 ++++++++++++++++++	5.07E-07	2.139	100.00000	10
11 ++++++++++++++++	2.37E-07		100.00000	11
12 +	0.00E+00		100.00000	12
13 +	0.00E+00		100.00000	13
14 +	0.00E+00		100.00000	14
15 +	0.00E+00		100.00000	15
16 +	0.00E+00		100.00000	16
17 +	0.00E+00		100.00000	17
18 +	0.00E+00		100.00000	18
19 +	0.00E+00		100.00000	19
20 +	0.00E+00		100.00000	20
21 +	0.00E+00		100.00000	21

[222]Table 10-2 is generated with GO Input file P25_EX5.COM stored in directory ERA$GO.

22 +			0.00E+00	100.00000 22
23 +			0.00E+00	100.00000 23
24 +			0.00E+00	100.00000 24
25 +			0.00E+00	100.00000 25
26 +			0.00E+00	100.00000 26
27 +			0.00E+00	100.00000 27
28 +			0.00E+00	100.00000 28
29 +			0.00E+00	100.00000 29
30 +			0.00E+00	100.00000 30

NUMERICAL RANK = 8

* SINGULAR VALUE TRUNCATION OCCURRED AT ORDER = 8 *

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (2)	OUTPUT (30)		MPC-W	MPC-U	PRC		ARATIO		RECIP-PROCITY	MSR,%
1	1	10.000**	1.000	(1.000)	:	100.00**	100.00	2	30	:	100.00	100.00	1000	:	0.798	:	100.0	41.1
2	2	15.000	1.000	(1.000)	:	76.07	100.00	2	30	:	76.08	25.92	862	:	0.712	:	99.0	59.1
3	3	15.000+	1.000	(1.000)	:	81.10+	100.00	2	30	:	81.10	25.99	866	:	0.712	:	99.2	62.4
4	4	20.000**	1.000	(1.000)	:	100.00**	100.00	2	30	:	100.00	100.00	1000	:	0.636	:	100.0	32.2

VAX EXECUTION STATISTICS:

COMPUTER NODENAME AND TYPE: SDBHR, VAXstation 3100-M76/GPX

ELAPSED: 0 00:00:08.62 CPU: 0:00:04.06 BUFIO: 73 DIRIO: 121 FAULTS: 996

START DATE/TIME: 21-MAR-1994 13:01
END DATE/TIME: 21-MAR-1994 13:01

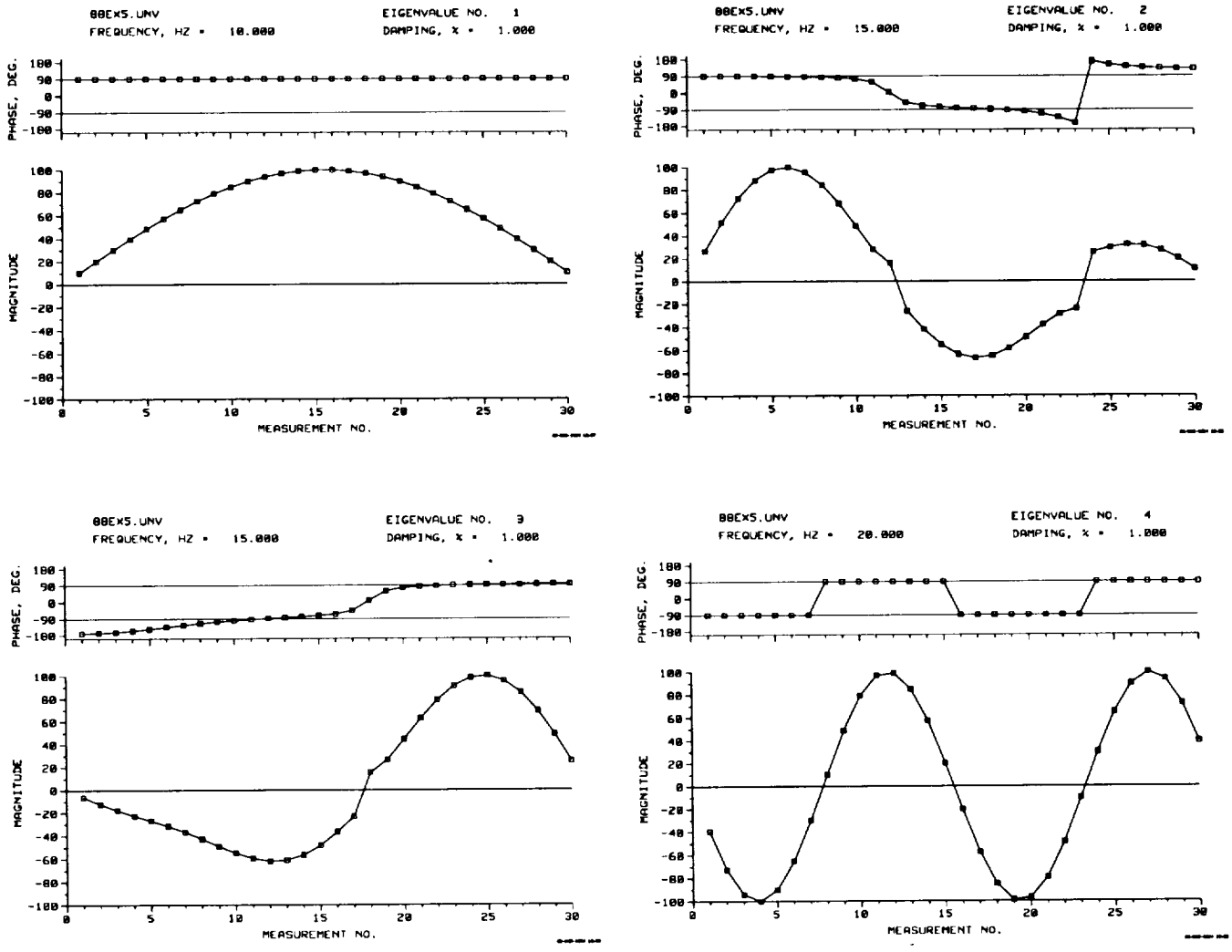


Fig. 10-2. Mode Shape Results for Example Problem EX005 (Compare With True Mode Shapes, Fig. 10-1) [G5_EX5.COM]

88EX4.UNV		-- 88EX5.UNV -->			
	|	1	2	3	4
	V	10.000	15.000	15.000	20.000
1	10.000	100*	0	0	0
2	15.000	0	39	70	0
3	15.001	0	61	30	0
4	20.000	0	0	0	100*

Table 10-2. MAC Correlation of EX004 (True) and EX005 Mode Shapes

10.6 Example Problem EX006

This example demonstrates the difficulty identifying an almost-repeated eigenvalue (15.0 and 15.001 Hz) **with single-input data**. (In Section 10.4, example problem EX004 showed exact identification of all modal parameters using 2-input data). Identification of repeated modes of multiplicity m requires at least m linearly independent inputs and at least m linearly independent outputs, ref. discussion at beginning of Section 10.4.

Program MIMO generates free-response time histories for 1 input and 30 outputs with the following parameters:[223]

Mode 1		**Mode 2**	
Frequency:	10 Hz	Frequency:	15 Hz
Damping:	1.0 %	Damping:	1.0 %
Amplitude:	1.0	Amplitude:	1.0
Mode 3		**Mode 4**	
Frequency:	15.001 Hz	Frequency:	20 Hz
Damping:	1.0 %	Damping:	1.0 %
Amplitude:	1.0	Amplitude:	1.0

These parameters are defined in file EX006.COM and can be easily modified by the user. Here is a listing of file EX006.COM:

```
$! EX006. ILLUSTRATE DIFFICULTY TO I.D. ALMOST-REPEATED EIGENVALUES
$!        W/ SINGLE-INPUT ANALYSIS
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO PROGRAM
$!
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
$!
$ MIMO
ERAEX6.OUT
 &MIMOIN
 T1NAMS='T1EX6_IC1'
 PNOISE = 0
 NIC = 1, INLOC = 7
 NST = 30
 NTIM = 1024
 SF = 100.
 NMODES = 4
 FREQ = 10.0, 15.0, 15.001, 20.0
 ZETAP  = 4*1.0
 AMODES = 4*1.0
 NPTMSR = 43
 &END
```

[223]Program MIMO calculates the free-response histories using Eq. 9-2.

```
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX6.ERA []
$ @ERA EX6
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX6.ERA:

```
$!  EX6.ERA:  EXAMPLE #6
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX6
$!
$ INPUT1:=EX6_IC1
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=30/
S/MRH=/MRH=150/
S/MIC=/MIC=1/
S/MST=/MST=30/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=100
 NUMRNK=1,ITAPES=88
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!            [ALWAYS USE EXACTLY 5 LINES]
$!
ILLUSTRATE IDENTIFICATION OF ALMOST REPEATED EIGENVALUE (15 & 15.001 HZ)
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX6:  EXAMPLE #6
```

The ERA analysis required approximately 3 seconds of CPU time on the author's VAXstation 3100 computer.

The results appear at the end of the Tape50 output file listed below (partial file). **ERA identifies the frequency and damping of modes 1 and 4 exactly. Frequency and damping results for modes 2 and 3, however, have slight error. Singular-value truncation occurs automatically at Order = 8, corresponding to 4 modes. Note, however, that the singular-value drop (D(N)/D(N+1)) at 6 singular values is approximately equal to that at 8 singular values. This result indicates that the data is also well represented by a 6th-order model, corresponding to only 3 modes.**

Fig. 10-3 shows the corresponding mode shapes plotted using GO Input file G5_EX6.COM. **Mode shapes 1 and 4 are identified exactly. Mode shapes 2 and 3 (for the almost-repeated mode at 15 Hz), however, are linear combinations of the 2 original shapes (shown in Fig. 10-1). Additional separation in natural frequency (or damping) or additional inputs are necessary to uniquely identify these 2 mode shapes.** The linear relationship of identified and true modes is quantified in Table 10-3 using the Modal Assurance Criterion (MAC).[224] Identified mode shape 2 (EX006) correlates 83% with original mode 2 (EX004) and 17% with original mode 3. Identified mode shape 3 correlates 49% with original mode 2 and 50% with original mode 3. In both cases, the sum of the modal contributions equals 100% (within numerical roundoff).

Note that the identified phase angles of mode 3 (Fig. 10-3) are significantly different from the classical ± 90° normal-mode characteristic. In practice, this behavior clearly signifies identification uncertainty. The Modal Phase Collinearity (and CMI) values drop accordingly.

File 50EX6.LIS (partial)

```
                                                                                                                  CUMULATIVE
                                                                                                                    % OF
SINGULAR VALUES, D():                                                                                  D(N)/D(1)   D(N)/D(N+1)  VARIANCE   N

  1 ******************************************************************************************  1.00E+00      1.353   49.70505   1
  2 ***************************************************************************************  7.39E-01      1.509   76.86046   2
  3 ***************************************************************************************  4.90E-01      1.235   88.77966   3
  4 ***************************************************************************************  3.97E-01      1.849   96.59443   4
  5 ***************************************************************************************  2.14E-01      1.430   98.88121   5
  6 ***************************************************************************************  1.50E-01    537.297   99.99999   6
  7 ***************************************************                                       2.79E-04      1.468  100.00000   7
  8 ***************************************************                                       1.90E-04*   407.697  100.00000   8

  9 XXXXXXXXXXXXXXXXXXX                                                                     4.67E-07      1.091  100.00000   9
 10 +++++++++++++++++++                                                                     4.28E-07      1.517  100.00000  10
 11 ++++++++++++++++                                                                        2.82E-07      1.475  100.00000  11
 12 +++++++++++++++                                                                         1.91E-07             100.00000  12
 13 +                                                                                       0.00E+00             100.00000  13
```

[224]Table 10-3 is generated with GO Input file P25_EX6.COM stored in directory ERA$GO.

14 +	0.00E+00	100.00000	14
15 +	0.00E+00	100.00000	15
16 +	0.00E+00	100.00000	16
17 +	0.00E+00	100.00000	17
18 +	0.00E+00	100.00000	18
19 +	0.00E+00	100.00000	19
20 +	0.00E+00	100.00000	20
21 +	0.00E+00	100.00000	21
22 +	0.00E+00	100.00000	22
23 +	0.00E+00	100.00000	23
24 +	0.00E+00	100.00000	24
25 +	0.00E+00	100.00000	25
26 +	0.00E+00	100.00000	26
27 +	0.00E+00	100.00000	27
28 +	0.00E+00	100.00000	28
29 +	0.00E+00	100.00000	29
30 +	0.00E+00	100.00000	30

NUMERICAL RANK = 8

* SINGULAR VALUE TRUNCATION OCCURRED AT ORDER = 8 *

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	OUTPUT (30)		MPC-W	MPC-U	PRC		ARATIO	RECIP-PROCITY	MSR,%
1	1	10.000**	1.000	(1.000)	:	99.99**	99.99	1	30	:	100.00	100.00	1000	:	0.726	:-999.0	45.8
2	2	15.000**	1.004	(1.003)	:	99.33**	99.90	1	30	:	99.43	95.25	976	:	0.617	:-999.0	79.1
3	3	15.002	0.998	(1.000)	:	9.30	99.80	1	30	:	9.32	1.05	556	:	0.618	:-999.0	37.6
4	4	20.000**	1.000	(1.000)	:	100.00**	100.00	1	30	:	100.00	100.00	1000	:	0.527	:-999.0	19.1

VAX EXECUTION STATISTICS:

COMPUTER NODENAME AND TYPE: SDBHR, VAXstation 3100-M76/GPX

ELAPSED: 0 00:00:07.44 CPU: 0:00:03.27 BUFIO: 58 DIRIO: 109 FAULTS: 947

START DATE/TIME: 21-MAR-1994 14:01
END DATE/TIME: 21-MAR-1994 14:01

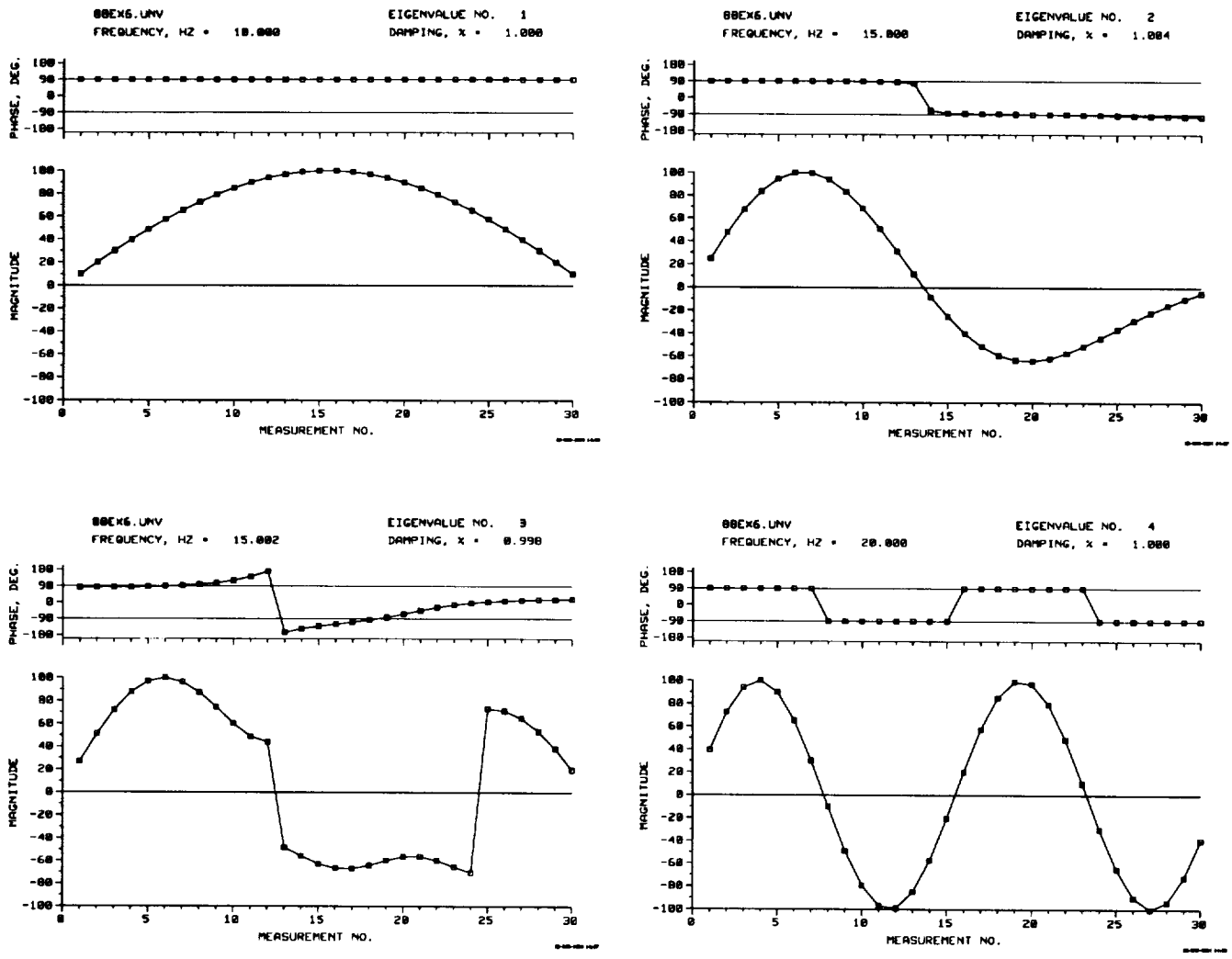


Fig. 10-3. Mode Shape Results for Example Problem EX006 (Compare With True Mode Shapes, Fig. 10-1) [G5_EX6.COM]

88EX4.UNV		-- 88EX6.UNV -->			
	1	2	3	4	
	V	10.000	15.000	15.002	20.000
1	10.000	100*	0	0	0
2	15.000	0	83	49	0
3	15.001	0	17	50	0
4	20.000	0	0	0	100*

Table 10-3. MAC Correlation of EX004 (True) and EX006 Mode Shapes

10.7 Example Problem EX007

The transformation of z-domain eigenvalues to s-domain eigenvalues (Eq. 2-33) is not unique. Writing Eq. 2-33 in terms of real and imaginary parts:

$$z = a + jb = e^{s(N_1\Delta t)} = e^{(\sigma + j\omega_d)(N_1\Delta t)} \tag{10-2}$$

where:
- z = z-domain eigenvalue
- a = real part of z
- b = imaginary part of z
- s = s-domain eigenvalue
- σ = modal damping rate (rad/sec)
- ω_d = damped natural frequency (rad/sec)
- N_1 = ERA analysis parameter N1 (ref. Chapter 6).
- Δt = data sampling interval (sec)
- j = $\sqrt{-1}$

Thus,

$$a = e^{\sigma\Delta t}\cos(\omega_d N_1 \Delta t)$$

and (10-3)

$$b = e^{\sigma\Delta t}\sin(\omega_d N_1 \Delta t)$$

from which

$$\sigma = \frac{1}{2N_1\Delta t}\ln(a^2 + b^2)$$

and (10-4)

$$\omega_d = \frac{1}{N_1\Delta t}\tan^{-1}\left(\frac{b}{a}\right)$$

Note: N1 is the number of data samples between the 2 generalized Hankel matrices used in the ERA solution (Eq. 2-17). **The normal (default) value of N1 is 1.**

The arctangent function is multi-valued (repetitive every π radians). Therefore,

$$\omega_d = \frac{1}{N_1\Delta t}\left[\tan^{-1}\left(\frac{b}{a}\right) + K\pi\right] \tag{10-5}$$

where $0 < \tan^{-1}\left(\frac{b}{a}\right) < \pi$ and $K = 0,1,2,\cdots$.

In software terminology (ref. Chapter 6), $K+1$ = ISTRIP, where **the default value of analysis parameter ISTRIP = 1**. Values of ISTRIP > 1 can be specified in Field 4 of the ERA User Input file (ref. Section 4.3). **If all measured responses satisfy the Nyquist sampling criterion of at least 2 data samples per cycle (normally the case), the default value of ISTRIP = 1 is appropriate.**

This example program demonstrates the use of ISTRIP > 1. Program MIMO generates free-response time histories at a sampling frequency of 100 Hz (Nyquist frequency = 50 Hz) for 1 input and 30 outputs with the following parameters:[225]

Mode 1		**Mode 2**	
Frequency:	10 Hz	Frequency:	60 Hz
Damping:	1.0 %	Damping:	1.0 %
Amplitude:	1.0	Amplitude:	1.0

Mode 3	
Frequency:	120 Hz
Damping:	1.0 %
Amplitude:	1.0

Modes 2 and 3 are above the Nyquist frequency of 50 Hz. ISTRIP = 1 is appropriate for mode 1. However, ISTRIP = 2 is appropriate for mode 2, and ISTRIP = 3 is appropriate for mode 3. For demonstration purposes, this example problem uses ISTRIP = 3.

ERA identifies damped natural frequencies and modal damping factors (fraction of critical damping) as follows:

$$f_d = \frac{\omega_d}{2\pi}$$

and (10-6)

$$\zeta = -\frac{\sigma}{\sqrt{\sigma^2 + \omega_d^2}}$$

Thus, both f_d and ζ vary as a function of ISTRIP.

The data parameters shown above are defined in file EX007.COM and can be easily modified by the user. Here is a listing of file EX007.COM:

```
$! EX007. ILLUSTRATE CORRECT I.D. OF ALIASED DATA USING ISTRIP > 1
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO PROGRAM
$!
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
```

[225]Program MIMO calculates the free-response histories using Eq. 9-2.

```
$!
$ MIMO
ERAEX7.OUT
 &MIMOIN
 T1NAMS='T1EX7'
 PNOISE = 0
 NIC = 1, INLOC = 7
 NST = 30
 NTIM = 1024
 SF = 100.
 NMODES = 3
 FREQ = 10.0,   60.0,  120.0
 ZETAP  = 3*1.0
 AMODES = 3*1.0
 NPTMSR = 43
 &END
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX7.ERA []
$ @ERA EX7
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX7.ERA:

```
$!  EX7.ERA:  EXAMPLE #7
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX7
$!
$ INPUT1:=EX7
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=30/
S/MRH=/MRH=150/
S/MIC=/MIC=1/
S/MST=/MST=30/
S/MTIM=/MTIM=1024/
```

```
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                        OF AVAILABLE PARAMETERS]
$!
 SF=100
 MIDOPT=1,NUMRNK=1
 ISTRIP=3,IPREVS=1,ITAPES=88
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!              [ALWAYS USE EXACTLY 5 LINES]
$!
ILLUSTRATE CORRECT I.D. OF ALIASED DATA USING ISTRIP > 1
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX7:  EXAMPLE #7
```

The ERA analysis required approximately 3 seconds of CPU time on the author's VAXstation 3100 computer.

The results appear on the Tape50 output file listed below (partial file). **Singular-value truncation occurs automatically at Order = 6, corresponding to 3 modes.** All 6 eigenvalues (3 complex-conjugate pairs) are printed for ISTRIP = 1, 2, and 3 because optional analysis parameter IPREVS = 1 appears in Field 4 of the User Input file (ref. Chapter 6). **ERA identifies all frequency and damping values exactly at the appropriate value of ISTRIP. Bold type highlights these results. In the section "Identification Results Sorted by Frequency" only the results for the 120 Hz mode are correct because this list uses ISTRIP = 3 as specified in the User Input file.**

Fig. 10-4 shows the corresponding mode shapes plotted using GO Input file G5_EX7.COM. All mode shapes are identified exactly. However (as explained above), only the 120 Hz mode has correct frequency and damping because the ERA analysis uses ISTRIP = 3.

File 50EX7.LIS (partial)

```
                                                                                                                  CUMULATIVE
SINGULAR VALUES, D():                                                                                              % OF
                                                                                                  D(N)/D(1)  D(N)/D(N+1) VARIANCE   N

  1 ***************************************************************************************** 1.00E+00      1.030   27.40784   1
  2 ***************************************************************************************** 9.71E-01      1.204   53.25214   2
  3 ************************************************************************************** 8.06E-01      1.092   71.07386   3
  4 ************************************************************************************** 7.39E-01      1.316   86.03018   4
  5 ************************************************************************************** 5.61E-01      1.272   94.66290   5
  6 ************************************************************************************** 4.41E-01* 2.352E+05  100.00000   6

  7 XXXXXXXXXXXXXXXXXXXXXXXXXX                                                                1.88E-06      1.084  100.00000   7
  8 ++++++++++++++++++++++++++                                                                1.73E-06      1.370  100.00000   8
```

```
 9 ++++++++++++++++++++++++
10 ++++++++++++++++++++++++
11 ++++++++++++++++++++++++
12 ++++++++++++++++++++++
13 ++++++++++++++++++++
14 ++++++++++++++++++
15 ++++++++++++++++++
16 ++++++++++++++++
17 ++++++++++++++
18 +
19 +
20 +
21 +
22 +
23 +
24 +
25 +
26 +
27 +
28 +
29 +
30 +
```

1.26E-06	1.104	100.00000	9
1.15E-06	1.007	100.00000	10
1.14E-06	1.260	100.00000	11
9.03E-07	1.387	100.00000	12
6.51E-07	1.114	100.00000	13
5.84E-07	1.075	100.00000	14
5.43E-07	1.560	100.00000	15
3.48E-07	1.359	100.00000	16
2.56E-07		100.00000	17
0.00E+00		100.00000	18
0.00E+00		100.00000	19
0.00E+00		100.00000	20
0.00E+00		100.00000	21
0.00E+00		100.00000	22
0.00E+00		100.00000	23
0.00E+00		100.00000	24
0.00E+00		100.00000	25
0.00E+00		100.00000	26
0.00E+00		100.00000	27
0.00E+00		100.00000	28
0.00E+00		100.00000	29
0.00E+00		100.00000	30

NUMERICAL RANK = 6

* SINGULAR VALUE TRUNCATION OCCURRED AT ORDER = 6 *

* * * ISTRIP = 3. S-PLANE EIGENVALUES FOR ISTRIP = 1 TO 3

* * * ARE PRINTED BELOW FOR EACH Z-PLANE EIGENVALUE:

SIGMA = REAL PART OF S-PLANE EIGENVALUE, RAD/SEC
WD = IMAG PART OF S-PLANE EIGENVALUE, RAD/SEC
WN = MAGNITUDE OF S-PLANE EIGENVALUE, RAD/SEC
SIGMA-HZ = DAMPING RATE, HZ (SIGMA/2PI)
FD-HZ = DAMPED NATURAL FREQUENCY, HZ (WD/2PI)
FN-HZ = UNDAMPED NATURAL FREQUENCY, HZ (WN/2PI)
ZETA-% = DAMPING FACTOR (C/CC), %
ZREAL = REAL PART OF Z-PLANE EIGENVALUE, DIMENSIONLESS
ZIMAG = IMAG PART OF Z-PLANE EIGENVALUE, "
ZMAG = MAGNITUDE OF Z-PLANE EIGENVALUE, "
ZPHSD = PHASE ANG OF Z-PLANE EIGENVALUE, DEG

EIGENVALUES:

	SIGMA	WD	WN	SIGMA-HZ	FD-HZ	FN-HZ	ZETA-%	ZREAL	ZIMAG	ZMAG	ZPHSD
1	-6.2831E-01	6.2832E+01	6.2835E+01	-1.000E-01	**1.00000E+01**	1.00005E+01	**9.999E-01**	8.039E-01	5.841E-01	9.937E-01	3.600E+01
1	-6.2831E-01	5.6549E+02	5.6549E+02	-1.000E-01	9.00000E+01	9.00001E+01	1.111E-01	8.039E-01	5.841E-01	9.937E-01	3.240E+02
1	-6.2831E-01	6.9115E+02	6.9115E+02	-1.000E-01	1.10000E+02	1.10000E+02	9.091E-02	8.039E-01	5.841E-01	9.937E-01	3.960E+02
2	-6.2831E-01	-6.2832E+01	6.2835E+01	-1.000E-01	-1.00000E+01	1.00005E+01	9.999E-01	8.039E-01	-5.841E-01	9.937E-01	-3.600E+01
2	-6.2831E-01	6.9115E+02	6.9115E+02	-1.000E-01	1.10000E+02	1.10000E+02	9.091E-02	8.039E-01	-5.841E-01	9.937E-01	3.960E+02
2	-6.2831E-01	5.6549E+02	5.6549E+02	-1.000E-01	9.00000E+01	9.00001E+01	1.111E-01	8.039E-01	-5.841E-01	9.937E-01	3.240E+02
3	-7.5402E+00	1.2566E+02	1.2589E+02	-1.200E+00	2.00000E+01	2.00360E+01	5.990E+00	2.866E-01	8.820E-01	9.274E-01	7.200E+01
3	-7.5402E+00	5.0265E+02	5.0271E+02	-1.200E+00	8.00000E+01	8.00090E+01	1.500E+00	2.866E-01	8.820E-01	9.274E-01	2.880E+02
3	-7.5402E+00	7.5398E+02	7.5402E+02	-1.200E+00	**1.20000E+02**	1.20006E+02	**1.000E+00**	2.866E-01	8.820E-01	9.274E-01	4.320E+02
4	-7.5402E+00	-1.2566E+02	1.2589E+02	-1.200E+00	-2.00000E+01	2.00360E+01	5.990E+00	2.866E-01	-8.820E-01	9.274E-01	-7.200E+01
4	-7.5402E+00	7.5398E+02	7.5402E+02	-1.200E+00	1.20000E+02	1.20006E+02	1.000E+00	2.866E-01	-8.820E-01	9.274E-01	4.320E+02
4	-7.5402E+00	5.0265E+02	5.0271E+02	-1.200E+00	8.00000E+01	8.00090E+01	1.500E+00	2.866E-01	-8.820E-01	9.274E-01	2.880E+02
5	-3.7701E+00	2.5133E+02	2.5136E+02	-6.000E-01	4.00000E+01	4.00045E+01	1.500E+00	-7.791E-01	5.660E-01	9.630E-01	1.440E+02
5	-3.7701E+00	3.7699E+02	3.7701E+02	-6.000E-01	**6.00000E+01**	6.00030E+01	**1.000E+00**	-7.791E-01	5.660E-01	9.630E-01	2.160E+02
5	-3.7701E+00	8.7965E+02	8.7965E+02	-6.000E-01	1.40000E+02	1.40001E+02	4.286E-01	-7.791E-01	5.660E-01	9.630E-01	5.040E+02
6	-3.7701E+00	-2.5133E+02	2.5136E+02	-6.000E-01	-4.00000E+01	4.00045E+01	1.500E+00	-7.791E-01	-5.660E-01	9.630E-01	-1.440E+02
6	-3.7701E+00	8.7965E+02	8.7965E+02	-6.000E-01	1.40000E+02	1.40001E+02	4.286E-01	-7.791E-01	-5.660E-01	9.630E-01	5.040E+02
6	-3.7701E+00	3.7699E+02	3.7701E+02	-6.000E-01	6.00000E+01	6.00030E+01	1.000E+00	-7.791E-01	-5.660E-01	9.630E-01	2.160E+02

* NOTE: FMIN = 0.0000, SF = 100.0000, N1 = 1, ISTRIP = 3.

THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN 100.0000 & 150.0000 HZ

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%		EMACS >= 80% INPUT (1)	OUTPUT (30)		MPC-W	MPC-U	PRC		ARATIO	RECIP-PROCITY	MSR,%
1	1	110.000**	0.091	(0.091)	:	99.99**	99.99	:	1	30	:	100.00	100.00	1000	:	0.726	:-999.0	66.2
2	2	120.000**	1.000	(1.000)	:	100.00**	100.00	:	1	30	:	100.00	100.00	1000	:	0.021	:-999.0	38.6
3	3	140.000**	0.429	(0.429)	:	99.99**	99.99	:	1	30	:	100.00	100.00	1000	:	0.146	:-999.0	64.1

```
VAX EXECUTION STATISTICS:
-------------------------

COMPUTER NODENAME AND TYPE:  SDBHR,  VAXstation 3100-M76/GPX

ELAPSED:     0 00:00:07.82  CPU: 0:00:02.95  BUFIO: 61  DIRIO: 119  FAULTS: 946

START DATE/TIME:  29-MAR-1994 15:20
  END DATE/TIME:  29-MAR-1994 15:20
```

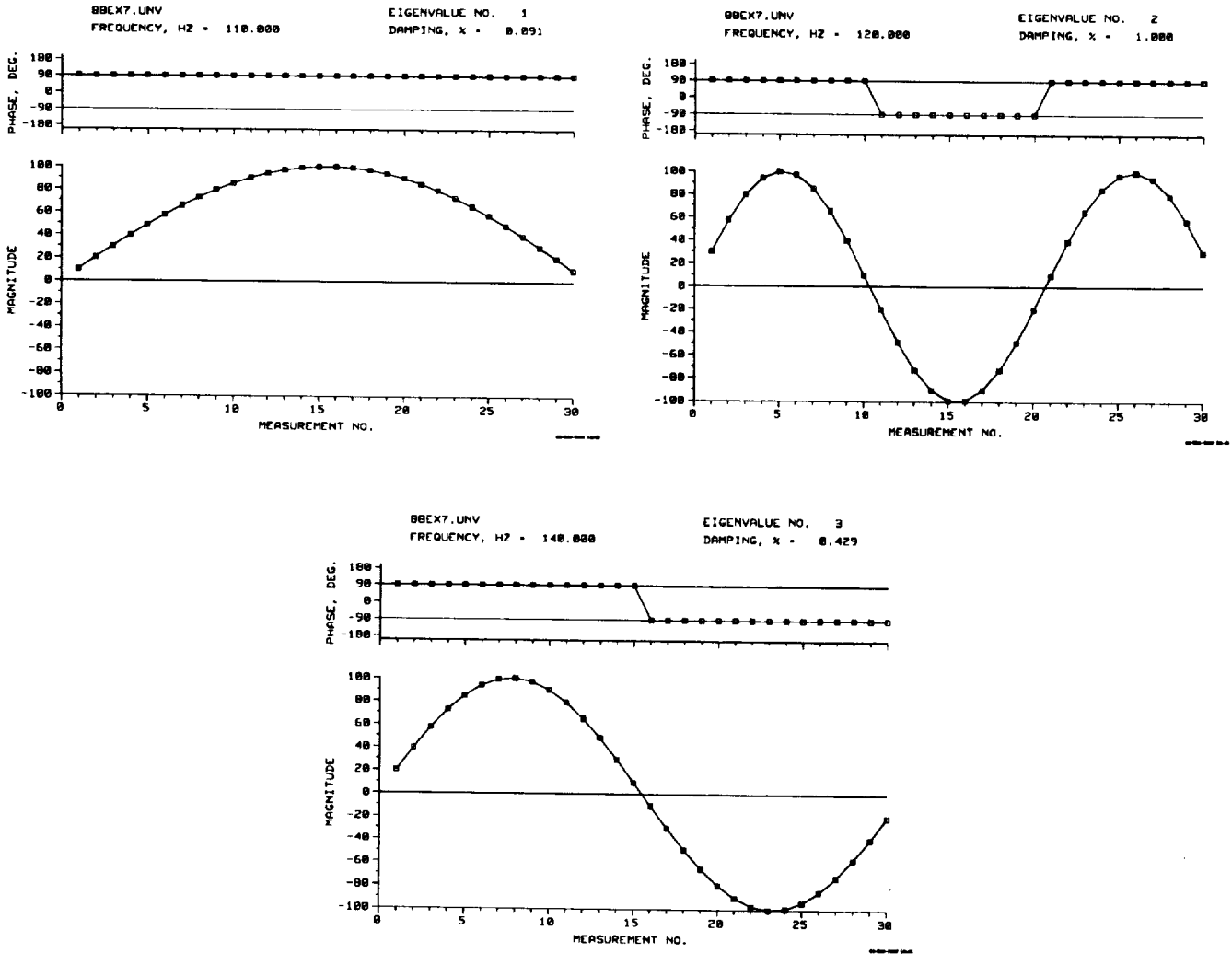


Fig. 10-4. Mode Shape Results for Example Problem EX007 (ISTRIP = 3) [G5_EX7.COM]

10.8 Example Problem EX008

Analysis parameters N2 and N3 (ref. Chapter 6) select the number of data samples between consecutive block rows and block columns, respectively, of the generalized Hankel matrices (Eq. 2-17). By default, N2 = N3 = 1. N2 and/or N3 values greater than 1 cause the data to be "stretched" in time which may improve identification accuracy of low-frequency modes. **However, N2, N3 values greater than 1 should be used cautiously (if at all) because lack of observability or controllability of certain modes can occur.**[226] This example problem demonstrates lack of observability. Lack of controllability is similar.

Program MIMO generates data for 3 modes with the following frequencies in Hz: 15, 25, and 35. The sampling frequency is 100 Hz. Note that the second mode (25 Hz) is at exactly one-half the Nyquist frequency of 50 Hz. It is not observable if analysis parameter N2 = 2.

Here is a listing of file EX008.COM:

```
$! EX008. ILLUSTRATE INABILITY TO I.D. MONOPHASE MODE AT
$!        NYQUIST FREQ/2 = 25 HZ IF N2 = 2 (OR N3 = 2)
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO PROGRAM
$!
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
$!
$ MIMO
ERAEX8.OUT
 &MIMOIN
 T1NAMS='T1EX8'
 PNOISE = 0
 NIC = 1, INLOC = 7
 NST = 30
 NTIM = 1024
 SF = 100.
 NMODES = 3
 FREQ = 15, 25, 35
 ZETAP  = 3*1.0
 AMODES = 3*1.0
 NPTMSR = 43
 &END
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX8.ERA []
```

[226] To avoid this problem altogether, an $N1 = N2 = N3$ value of $\overline{N}$ should be used only if the data is bandlimited to the frequency range from 0 to $\frac{SF/2}{\overline{N}}$ Hz, where $SF = \frac{1}{\Delta t}$ is the data sampling frequency.

```
$ @ERA EX8
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX8.ERA:

```
$!  EX8.ERA:  EXAMPLE #8
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX8
$!
$ INPUT1:=EX8
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=20/
S/MRH=/MRH=300/
S/MIC=/MIC=1/
S/MST=/MST=30/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                     OF AVAILABLE PARAMETERS]
$!
 SF=100
 MIDOPT=1,NUMRNK=1
 N2=2
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!            [ALWAYS USE EXACTLY 5 LINES]
$!
SHOW INABILITY TO I.D. NORMAL MODE AT NYQUIST FREQ/2 = 25 HZ IF N2=2 (OR N3=2)
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX8:  EXAMPLE #8
```

The ERA results appear on the Tape50 output file listed below. The ERA analysis used N2 = 2 so that the 25 Hz mode located at one-half the Nyquist frequency (SF/2) is not observable. It appears as a real eigenvalue rather than as a complex-conjugate pair of eigenvalues because the data is shifted by exactly one-half cycle (2 data points) between each consecutive block row in the generalized Hankel matrix.[227] Note that the singular values indicate that the order of the system is 5 (2 modes and 1 real eigenvalue). The modes at 15 and 35 Hz are accurately identified.

This anomaly occurs at N2-1 equally spaced frequencies in the frequency spectrum from 0 to the Nyquist frequency. It also occurs at N3-1 equally spaced frequencies in the frequency spectrum from 0 to the Nyquist frequency. In practice, N2 = N3 = N1 = 1 is normally used and recommended.

The next 2 example problems (EX009 and EX010) show 2 different ways that this anomaly is avoided while retaining N2 = 1.

File 50EX8.LIS

```
* * * ERA -- VERSION 931216 * * *

SHOW INABILITY TO I.D. NORMAL MODE AT NYQUIST FREQ/2 = 25 HZ IF N2=2 (OR N3=2)
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX8:  EXAMPLE #8


TAPE1 FILE NAMES:
----------------
   1. []T1EX8.DAT

ANALYSIS PARAMETERS:                                                                                                  DEFAULT
-------------------                                                                                                    VALUE
                  (MAX)                                                                                                -------
 NCH .......  20 (   20)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                              MCH
 NRH ....... 300 (  300)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                              MRH
 NIC .......   1 (    1)  - NO. OF INITIAL CONDITIONS (INPUTS)                                                          MIC
 NST .......  30 (   30)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                                   MST
*NTIM ......  56 ( 1024)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)                 -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                                 -
*WINDOW ....     0.550    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                                      -
 FMIN ......     0.000    - FMIN OF DATA (FOR "ZOOMED" DATA)                                                            0.0

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                        -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                        -
 IORFIR ....  50          - ORDER OF BANDPASS FIR FILTER                                                                 50

 NSFRST ....   1          - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                               1
 NSFLAG() ..              - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]        ALL 1
             1111111111 1111111111 1111111111
*NSTBOT ....  30          - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                         NST

 NGENTH ....   0          - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)    0
*NSTDTA ....  30          - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                                  -

 N1 ........   1          - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                               1
 N2 ........   2          - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                                   1
 N3 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                                   1
 N2LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                           10
 N3LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                           10
```

[227]This mode appears as a real eigenvalue because it is controllable but not observable. It would also appear as a real eigenvalue if N3 = 2 (instead), in which case the mode is observable but not controllable. If N2 = N3 = 2, the mode is both uncontrollable and unobservable and no eigenvalue whatsoever is obtained.

```
 NSKIP .....    0          - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                          0
 ISTRIP ....    1          - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                          1
 ICAS85 ....    1          - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                                   1
 DATABW ....  -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1     -

 MODELC ....    0          - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79      0
 MODELD ....    0          - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79      0
 NOAD79 ....    0          - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)          0

*RNKTL0 ....  1.79E-05     - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)                SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....-999           - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")                             -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  1.79E-05     - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                                  RNKTL0
 2. MXFLAG .    0          - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                         0
 3. POFVAR . 101.0000      - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                                99.999
 4. MXORDR .  20           - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                          0.75 * MIN(NRH,NCH)

 NUMRNK ....    1          -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BYPASSING CRITERIA 1-4 ABOVE         0

 MIDOPT ....    1          - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]                     0

 ITAPE(50) .    1          - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                                 1
 ITAPE(51) .    0          - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                                     0
 ITAPE(55) .    0          - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                         0
 ITAPE(79) .    0          - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                               0
  MXALL ....    0          -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                                 0
  MXHANK ...    0          -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                              0
  MXPDQT ...    0          -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                                  0
  MXMTM ....    0          -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT               0
  MXMOMC ...    0          -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                               0
  MXDATA ...    0          -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                                0
   MXDNTM ..-999           -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79          MTIM
   MXDNSF ..   1           -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                              1
   MXDNSL ..  30           -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                            NST
   MXDNIF ..   1           -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                              1
   MXDNIL ..   1           -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                            NIC
 ITAPE(80) .    0          - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...    0          - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80               0
 ITAPE(85) .    1          - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85          1
 ITAPE(88) .    0          - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                             0
 ITYDTA ....    3          - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                           3
 MSSCAL ....    2          - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES          2
 IREFTU ....    0          - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)      0
 T55CMI ....      1.0      - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                       1.0
 T88CMI ....      1.0      - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                       1.0

 MSTO50 ....    0          - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                        0
 MSPP50 ....    1          - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)                  1

 LOOPOP ....    0          - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                     0
  PAR(1) ... -999.00        -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                        -
  PAR(2) ... -999.00        -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                        -
  PAR(3) ... -999.00        -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                        -
  PAR(4) ... -999.00        -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                        -
  PAR(5) ... -999.00        -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                        -
*NCASES ....    1          - NO. OF CONSECUTIVE CASES TO RUN                                                                 1

 IPREMC ....    0          - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                        0
 IPRHRS ....    0          - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH 0
 IPRPDQ ....    0          - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                                 0
 IPRABC ....    0          - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                             0
 IPREVS ....    0          - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                                 0
 IPRREV ....    0          - IF IPRREV=1, PRINT TIME CONSTANTS & INITIAL AMPS OF REAL EIGENVALUES ON TAPE50                  0
 IPRDTA ....    0          - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                            0
 IPRPAR ....    0          - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                            0
 MSRTOT ....    0          - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                                 0

 IOMAC .....    0          - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1                 0
 ---------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ---------------------------------------------------------------


EX8:  EXAMPLE #8

CASE NO.   1:
------------

D(1) =   2.81721E+01

                                                                                                  CUMULATIVE
                                                                                                    % OF
SINGULAR VALUES, D():                                                          D(N)/D(1)  D(N)/D(N+1) VARIANCE   N
  1 **********************************************************************************************  1.00E+00     1.616   45.36563   1
  2 ********************************************************************************               6.19E-01     1.128   62.74753   2
  3 ***************************************************************************                    5.49E-01     1.036   76.41986   3
  4 ************************************************************************                       5.30E-01     1.085   89.16567   4
  5 ***********************************************************************                        4.89E-01* 4.929E+05  100.00000   5
```

```
 6 XXXXXXXXXXXXXXXXXXXXXX                 9.91E-07    1.206  100.00000   6
 7 ++++++++++++++++++++++                  8.22E-07    1.094  100.00000   7
 8 ++++++++++++++++++++++                  7.51E-07    1.199  100.00000   8
 9 ++++++++++++++++++++                    6.26E-07    1.051  100.00000   9
10 ++++++++++++++++++++                    5.96E-07    1.137  100.00000  10
11 ++++++++++++++++++++                    5.24E-07    1.056  100.00000  11
12 ++++++++++++++++++                      4.96E-07    1.057  100.00000  12
13 ++++++++++++++++++                      4.69E-07    1.307  100.00000  13
14 ++++++++++++++++++                      3.59E-07    1.260  100.00000  14
15 ++++++++++++++++                        2.85E-07    1.089  100.00000  15
16 ++++++++++++++++                        2.62E-07    1.143  100.00000  16
17 ++++++++++++++++                        2.29E-07           100.00000  17
18 +                                       0.00E+00           100.00000  18
19 +                                       0.00E+00           100.00000  19
20 +                                       0.00E+00           100.00000  20
```

NUMERICAL RANK = 5

* SINGULAR VALUE TRUNCATION OCCURRED AT ORDER = 5 *

INPUT (REFERENCE) COORDINATE CODES:

IC NO.	COORDINATE CODE	MEAS. NO.
1	1X+	1

* NOTE: FMIN = 0.0000, SF = 100.0000, N1 = 1, ISTRIP = 1.

THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN 0.0000 & 50.0000 HZ

IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	15.000+	1.000	(0.977)	87.03+	87.04	1	14	99.99	99.99	997	0.608	:-999.0	51.4
2	2	35.000+	1.000	(0.955)	81.93+	82.72	1	16	99.04	92.06	960	0.322	:-999.0	54.1

IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	15.000+	1.000	(0.977)	87.03+	87.04	1	14	99.99	99.99	997	0.608	:-999.0	51.4
2	2	35.000+	1.000	(0.955)	81.93+	82.72	1	16	99.04	92.06	960	0.322	:-999.0	54.1

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	15.000+	1.000	(0.977)	87.03+	87.04	1	14	99.99	99.99	997	0.608	:-999.0	51.4
2	2	35.000+	1.000	(0.955)	81.93+	82.72	1	16	99.04	92.06	960	0.322	:-999.0	54.1

VAX EXECUTION STATISTICS:

COMPUTER NODENAME AND TYPE: SDBRP, VAXstation 3100/GPX

ELAPSED: 0 00:00:12.39 CPU: 0:00:08.62 BUFIO: 52 DIRIO: 95 FAULTS: 952

```
START DATE/TIME:  19-APR-1994 15:52
  END DATE/TIME:  19-APR-1994 15:52
```

10.9 Example Problem EX009

In Example Problem EX008, the mode at one-half the Nyquist frequency (i.e., the mode at 25 Hz) is unobservable when N2 = 2. This anomaly occurs because the time-shifted mode-shape vector (i.e., the contribution of this mode in the observability matrix, Eq. 2-19) is a monophase vector. A monophase mode-shape vector has a rank of 1 rather than the normal value of 2. ERA identifies this mode as a real eigenvalue rather than as a complex-conjugate pair of eigenvalues because of the rank deficiency. Real eigenvalues have a frequency of 0 Hz.

This example demonstrates how the 25 Hz mode becomes observable if the mode shape components contain a slight amount of random phase shift (1 degree). This causes the time-shifted vector to have a rank of 2. All 3 modes (15, 25, and 35 Hz) are identified properly in this situation. It is reasonable to assume that experimental data sets normally contain at least 1 degree of random phase error (i.e., the structure has slightly non-monophase mode shapes).

The anomaly demonstrated in Example Problem EX008 occurs at N2-1 equally spaced frequencies in the frequency spectrum from 0 to the Nyquist frequency. It also occurs at N3-1 equally spaced frequencies in the frequency spectrum from 0 to the Nyquist frequency. In practice, N2 = N3 = N1 = 1 is normally used and recommended.

Here is a listing of file EX009.COM:

```
$! EX009. SAME AS EX008 EXCEPT WITH 1 DEGREE OF ADDED RANDOM PHASE ANGLE
$!          (TO GENERATE NON-MONOPHASE EIGENVECTORS)
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO PROGRAM
$!
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
$!
$ MIMO
ERAEX9.OUT
 &MIMOIN
 T1NAMS='T1EX9'
 PNOISE = 0
 NIC = 1, INLOC = 7
 NST = 30
 NTIM = 1024
 SF = 100.
 NMODES = 3
 FREQ = 15, 25, 35
 ZETAP  = 3*1.0
```

```
 AMODES = 3*1.0
 PRANDD = 1
 NPTMSR = 43
 &END
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX9.ERA []
$ @ERA EX9
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX9.ERA:

```
$!  EX9.ERA:  EXAMPLE #9
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX9
$!
$ INPUT1:=EX9
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=20/
S/MRH=/MRH=300/
S/MIC=/MIC=1/
S/MST=/MST=30/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                      OF AVAILABLE PARAMETERS]
$!
 SF=100
 MIDOPT=1,NUMRNK=1
 N2=2
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!             [ALWAYS USE EXACTLY 5 LINES]
$!
```

```
SAME AS EX008 EXCEPT MODES HAVE RANDOM PHASE ANGLE OF 1 DEG.
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX9:  EXAMPLE #9
```

There are 6 significant singular values because all 3 modes are now observable and controllable. Identified modal parameters appear near the end of the Tape50 listing shown below. All 3 modes are precisely identified.

File 50EX9.LIS

```
* * * ERA -- VERSION 931216 * * *


SAME AS EX008 EXCEPT MODES HAVE RANDOM PHASE ANGLE OF 1 DEG.
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX9:  EXAMPLE #9


TAPE1 FILE NAMES:
----------------
   1. []T1EX9.DAT

ANALYSIS PARAMETERS:                                                                                                    DEFAULT
----------------- ---                                                                                                    VALUE
                 (MAX)                                                                                                  -------
 NCH ....... 20 (   20)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                                  MCH
 NRH ....... 300 (  300)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                                 MRH
 NIC .......  1 (    1)  - NO. OF INITIAL CONDITIONS (INPUTS)                                                              MIC
 NST .......  30 (   30)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                                    MST
*NTIM ......  56 ( 1024)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)                  -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                                 -
*WINDOW ....     0.550    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                                      -
 FMIN ......     0.000    - FMIN OF DATA (FOR "ZOOMED" DATA)                                                            0.0

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                        -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                        -
 IORFIR ....  50          - ORDER OF BANDPASS FIR FILTER                                                                 50

 NSFRST ....   1          - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                               1
 NSFLAG() ..              - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]          ALL 1
          1111111111 1111111111 1111111111
*NSTBOT ....  30          - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                         NST

 NGENTH ....   0          - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)    0
*NSTDTA ....  30          - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                                  -

 N1 ........   1          - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                               1
 N2 ........   2          - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                                   1
 N3 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                                   1
 N2LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                            10
 N3LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                            10

 NSKIP .....   0          - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                       0
 ISTRIP ....   1          - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                       1
 ICAS85 ....   1          - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                                1
 DATABW ....  -999.000    - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1   -

 MODELC ....   0          - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79    0
 MODELD ....   0          - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79    0
 NOAD79 ....   0          - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)       0

*RNKTL0 ....  1.79E-05    - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)                SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....-999          - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")                          -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  1.79E-05    - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                                   RNKTL0
 2. MXFLAG .   0          - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                       0
 3. POFVAR . 101.0000     - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                                99.999
 4. MXORDR .  20          - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                          0.75 * MIN(NRH,NCH)

 NUMRNK ....   1          -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BYPASSING CRITERIA 1-4 ABOVE      0
```

```
 MIDOPT ....    1          - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]                    0

 ITAPE(50) .    1          - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                                1
 ITAPE(51) .    0          - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                                    0
 ITAPE(55) .    0          - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                        0
 ITAPE(79) .    0          - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                              0
  MXALL ....    0          -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                                0
  MXHANK ...    0          -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                              0
  MXPDQT ...    0          -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                                  0
  MXMTM ....    0          -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT               0
  MXMOMC ...    0          -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                               0
  MXDATA ...    0          -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                                0
   MXDNTM ..-999           -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79          MTIM
   MXDNSF ..   1           -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                            1
   MXDNSL ..  30           -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                          NST
   MXDNIF ..   1           -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                            1
   MXDNIL ..   1           -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                          NIC
 ITAPE(80) .    0          - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...    0          - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80              0
 ITAPE(85) .    1          - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85         1
 ITAPE(88) .    0          - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                            0
 ITYDTA ....    3          - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                          3
 MSSCAL ....    2          - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES         2
 IREFTU ....    0          - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)     0
 T55CMI ....  1.0          - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                      1.0
 T88CMI ....  1.0          - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                      1.0

 MSTO50 ....    0          - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                       0
 MSPP50 ....    1          - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)                 1

 LOOPOP ....    0          - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                    0
  PAR(1) ... -999.00        -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                       -
  PAR(2) ... -999.00        -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                       -
  PAR(3) ... -999.00        -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                       -
  PAR(4) ... -999.00        -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                       -
  PAR(5) ... -999.00        -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                       -
*NCASES ....    1          - NO. OF CONSECUTIVE CASES TO RUN                                                                1

 IPREMC ....    0          - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                       0
 IPRHRS ....    0          - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH  0
 IPRPDQ ....    0          - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                                0
 IPRABC ....    0          - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                            0
 IPREVS ....    0          - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                                0
 IPRREV ....    0          - IF IPRREV=1, PRINT TIME CONSTANTS & INITIAL AMPS OF REAL EIGENVALUES ON TAPE50                  0
 IPRDTA ....    0          - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                           0
 IPRPAR ....    0          - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                           0
 MSRTOT ....    0          - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                                0

 IOMAC .....    0          - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1                0
 ----------------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ----------------------------------------------------------------------


EX9:  EXAMPLE #9

CASE NO.   1:
------------

D(1) =   2.81693E+01

                                                                                                  CUMULATIVE
                                                                                                    % OF
SINGULAR VALUES, D():                                                          D(N)/D(1)  D(N)/D(N+1) VARIANCE   N

  1 ********************************************************************************************** 1.00E+00      1.615   45.35440   1
  2 ******************************************************************************************    6.19E-01      1.125   62.73803   2
  3 ***************************************************************************************      5.50E-01      1.041   76.48061   3
  4 ************************************************************************************         5.29E-01      1.083   89.16920   4
  5 *********************************************************************************            4.89E-01     45.514   99.99477   5
  6 ********************************************************************                         1.07E-02* 10633.735   100.00000   6

  7 XXXXXXXXXXXXXXXXXXXXXXX                                                                      1.01E-06      1.459   100.00000   7
  8 ++++++++++++++++++++                                                                         6.92E-07      1.021   100.00000   8
  9 ++++++++++++++++++++                                                                         6.78E-07      1.019   100.00000   9
 10 ++++++++++++++++++++                                                                         6.65E-07      1.037   100.00000  10
 11 ++++++++++++++++++++                                                                         6.41E-07      1.245   100.00000  11
 12 ++++++++++++++++++++                                                                         5.15E-07      1.068   100.00000  12
 13 ++++++++++++++++++                                                                           4.82E-07      1.072   100.00000  13
 14 ++++++++++++++++++                                                                           4.50E-07      1.187   100.00000  14
 15 ++++++++++++++++++                                                                           3.79E-07      1.287   100.00000  15
 16 ++++++++++++++++                                                                             2.94E-07      1.038   100.00000  16
 17 ++++++++++++++++                                                                             2.83E-07      1.054   100.00000  17
 18 ++++++++++++++++                                                                             2.69E-07      1.314   100.00000  18
 19 ++++++++++++++                                                                               2.05E-07              100.00000  19
 20 +                                                                                            0.00E+00              100.00000  20

                                NUMERICAL RANK =   6
                                ---------------------
```

* SINGULAR VALUE TRUNCATION OCCURRED AT ORDER = 6 *

INPUT (REFERENCE) COORDINATE CODES:

IC NO.	COORDINATE CODE	MEAS. NO.
1	1X+	1

* NOTE: FMIN = 0.0000, SF = 100.0000, N1 = 1, ISTRIP = 1.

THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN 0.0000 & 50.0000 HZ

IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):

E.V. NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	EMACS >= 80% OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1 3	35.000**	1.000	(1.000)	99.95**	99.99	1	30	99.96	99.96	991	0.305	:-999.0	54.1
2 2	25.000**	1.000	(1.000)	99.94**	99.98	1	30	99.96	99.96	991	0.428	:-999.0	67.9
3 1	15.000**	1.000	(1.000)	99.93**	99.99	1	30	99.93	99.94	988	0.601	:-999.0	51.3

IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):

E.V. NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	EMACS >= 80% OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1 2	25.000**	1.000	(1.000)	99.94**	99.98	1	30	99.96	99.96	991	0.428	:-999.0	67.9
2 3	35.000**	1.000	(1.000)	99.95**	99.99	1	30	99.96	99.96	991	0.305	:-999.0	54.1
3 1	15.000**	1.000	(1.000)	99.93**	99.99	1	30	99.93	99.94	988	0.601	:-999.0	51.3

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

E.V. NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	EMACS >= 80% OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1 1	15.000**	1.000	(1.000)	99.93**	99.99	1	30	99.93	99.94	988	0.601	:-999.0	51.3
2 2	25.000**	1.000	(1.000)	99.94**	99.98	1	30	99.96	99.96	991	0.428	:-999.0	67.9
3 3	35.000**	1.000	(1.000)	99.95**	99.99	1	30	99.96	99.96	991	0.305	:-999.0	54.1

VAX EXECUTION STATISTICS:

COMPUTER NODENAME AND TYPE: SDBRP, VAXstation 3100/GPX

ELAPSED: 0 00:00:12.64 CPU: 0:00:08.82 BUFIO: 52 DIRIO: 81 FAULTS: 984

START DATE/TIME: 20-APR-1994 08:09
END DATE/TIME: 20-APR-1994 08:10

10.10 Example Problem EX010

In Example Problem EX008, the mode at one-half the Nyquist frequency (i.e., the mode at 25 Hz) is unobservable when N2 = 2. This anomaly occurs because the time-shifted mode-shape vector (i.e., the contribution of this mode in the observability matrix, Eq. 2-19) is a monophase vector. A monophase mode-shape vector has a rank of 1 rather than the normal value of 2. ERA identifies this mode as a real eigenvalue rather than as a complex-conjugate pair of eigenvalues because of the rank deficiency. Real eigenvalues have a frequency of 0 Hz.

This example demonstrates how the 25 Hz mode becomes observable if the frequency is shifted slightly to 25.01 Hz. This causes the time-shifted mode-shape vector to have a rank of 2. All 3 modes (15, 25, and 35 Hz) are identified properly in this situation. It is reasonable to assume that experimental data sets do not normally have modes at EXACTLY one-half the Nyquist frequency.

The anomaly demonstrated in Example Problem EX008 occurs at N2-1 equally spaced frequencies in the frequency spectrum from 0 to the Nyquist frequency. It also occurs at N3-1 equally spaced frequencies in the frequency spectrum from 0 to the Nyquist frequency. In practice, N2 = N3 = N1 = 1 is normally used and recommended.

Here is a listing of file EX010.COM:

```
$! EX010. SAME AS EX008, WITH 25.0 HZ MODE MOVED TO 25.01 HZ
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO PROGRAM
$!
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
$!
$ MIMO
ERAEX10.OUT
 &MIMOIN
 T1NAMS='T1EX10'
 PNOISE = 0
 NIC = 1, INLOC = 7
 NST = 30
 NTIM = 1024
 SF = 100.
 NMODES = 3
 FREQ = 15.0, 25.01, 35.0
 ZETAP  = 3*1.0
 AMODES = 3*1.0
 NPTMSR = 43
 &END
$!
$! RUN ERA INTERACTIVELY
$!
```

```
$ COPY ERA$OEXS:EX10.ERA []
$ @ERA EX10
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX10.ERA:

```
$!  EX10.ERA:  EXAMPLE #10
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX10
$!
$ INPUT1:=EX10
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=20/
S/MRH=/MRH=300/
S/MIC=/MIC=1/
S/MST=/MST=30/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=100
 MIDOPT=1,NUMRNK=1
 N2=2
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!            [ALWAYS USE EXACTLY 5 LINES]
$!
SAME AS EX008 EXCEPT 25.0 HZ MODE MOVED TO 25.01 HZ
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX10:  EXAMPLE #10
```

File 50EX10.LIS

```
* * * ERA -- VERSION 931216 * * *

SAME AS EX008 EXCEPT 25.0 HZ MODE MOVED TO 25.01 HZ
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX10:  EXAMPLE #10


TAPE1 FILE NAMES:
----------------
   1. []T1EX10.DAT

ANALYSIS PARAMETERS:                                                                                                    DEFAULT
-------------------                                                                                                     VALUE
                (MAX)                                                                                                   -------
 NCH ....... 20 (   20)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                                 MCH
 NRH ....... 300 (  300)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                               MRH
 NIC .......   1 (    1)  - NO. OF INITIAL CONDITIONS (INPUTS)                                                          MIC
 NST .......  30 (   30)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                                 MST
*NTIM ......  56 ( 1024)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)               -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                               -
*WINDOW ....     0.550    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                                    -
 FMIN ......     0.000    - FMIN OF DATA (FOR "ZOOMED" DATA)                                                          0.0

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                      -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                      -
 IORFIR ....  50          - ORDER OF BANDPASS FIR FILTER                                                               50

 NSFRST ....  1           - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                             1
 NSFLAG() ..              - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]        ALL 1
          1111111111 1111111111 1111111111                                                                           NST
*NSTBOT ....  30          - NO. OF OUTPUTS ACTIVATED IN NSFLAG()

 NGENTH ....   0          - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)  0
*NSTDTA ....  30          - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                                -

 N1 ........   1          - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                             1
 N2 ........   2          - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                                 1
 N3 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                                 1
 N2LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                          10
 N3LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                          10

 NSKIP .....   0          - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                     0
 ISTRIP ....   1          - ASSUMED 2-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                     1
 ICAS85 ....   1          - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                              1
 DATABW ....  -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1  -

 MODELC ....   0          - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 MODELD ....   0          - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 NOAD79 ....   0          - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)     0

*RNKTL0 ....  1.79E-05    - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)          SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....-999          - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")                        -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  1.79E-05    - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                                  RNKTL0
 2. MXFLAG .   0          - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                     0
 3. POFVAR . 101.0000     - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                               99.999
 4. MXORDR .  20          - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                  0.75 * MIN(NRH,NCH)

 NUMRNK ....   1          -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BYPASSING CRITERIA 1-4 ABOVE    0

 MIDOPT ....   1          - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]                0

 ITAPE(50) .   1          - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                             1
 ITAPE(51) .   0          - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                                 0
 ITAPE(55) .   0          - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                     0
 ITAPE(79) .   0          - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                           0
  MXALL ....   0          -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                             0
  MXHANK ...   0          -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                           0
  MXPDQT ...   0          -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                               0
  MXMTM ....   0          -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT            0
  MXMOMC ...   0          -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                            0
  MXDATA ...   0          -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                             0
   MXDNTM ..-999          -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79       MTIM
   MXDNSF ..   1          -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                           1
   MXDNSL ..  30          -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                         NST
   MXDNIF ..   1          -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                           1
   MXDNIL ..   1          -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                         NIC
 ITAPE(80) .   0          - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...   0          - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80           0
```

```
 ITAPE(85) .    1          - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85          1
 ITAPE(88) .    0          - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                              0
 ITYDTA ....    3          - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                            3
 MSSCAL ....    2          - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES           2
 IREFTU ....    0          - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)       0
 T55CMI ....      1.0      - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                        1.0
 T88CMI ....      1.0      - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                        1.0

 MSTO50 ....    0          - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                         0
 MSPP50 ....    1          - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)                   1

 LOOPOP ....    0          - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                      0
  PAR(1) ... -999.00        -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                          -
  PAR(2) ... -999.00        -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                          -
  PAR(3) ... -999.00        -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                          -
  PAR(4) ... -999.00        -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                          -
  PAR(5) ... -999.00        -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                          -
*NCASES ....    1          - NO. OF CONSECUTIVE CASES TO RUN                                                                  -
                                                                                                                             1

 IPREMC ....    0          - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                         0
 IPRHRS ....    0          - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH 0
 IPRPDQ ....    0          - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                                  0
 IPRABC ....    0          - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                              0
 IPREVS ....    0          - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                                  0
 IPRREV ....    0          - IF IPRREV=1, PRINT TIME CONSTANTS & INITIAL AMPS OF REAL EIGENVALUES ON TAPE50                   0
 IPRDTA ....    0          - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                             0
 IPRPAR ....    0          - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                             0
 MSRTOT ....    0          - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                                  0
                                                                                                                             0
 IOMAC .....    0          - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1                  0
 ------------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ------------------------------------------------------------------


EX10:  EXAMPLE #10

CASE NO.   1:
------------

D(1) =   2.81692E+01

SINGULAR VALUES, D():                                                                                  CUMULATIVE
                                                                                                          % OF
                                                                          D(N)/D(1)   D(N)/D(N+1)      VARIANCE    N
  1 **********************************************************************************************  1.00E+00      1.615     45.35934    1
  2 *********************************************************************************************  6.19E-01      1.127     62.74072    2
  3 ********************************************************************************************  5.49E-01      1.036     76.41453    3
  4 *******************************************************************************************  5.30E-01      1.085     89.16463    4
  5 ********************************************************************************************  4.89E-01    108.777     99.99908    5
  6 ************************************************************                                   4.49E-03*  4887.653    100.00000    6

  7 XXXXXXXXXXXXXXXXXXXXX                                                                         9.19E-07      1.426    100.00000    7
  8 ++++++++++++++++++++                                                                          6.45E-07      1.120    100.00000    8
  9 ++++++++++++++++++++                                                                          5.76E-07      1.024    100.00000    9
 10 ++++++++++++++++++++                                                                          5.62E-07      1.101    100.00000   10
 11 ++++++++++++++++++++                                                                          5.11E-07      1.175    100.00000   11
 12 ++++++++++++++++++                                                                            4.34E-07      1.016    100.00000   12
 13 ++++++++++++++++++                                                                            4.27E-07      1.275    100.00000   13
 14 ++++++++++++++++                                                                              3.35E-07      1.032    100.00000   14
 15 ++++++++++++++++                                                                              3.25E-07      1.243    100.00000   15
 16 ++++++++++++++++                                                                              2.61E-07      1.038    100.00000   16
 17 ++++++++++++++++                                                                              2.52E-07      1.184    100.00000   17
 18 ++++++++++++++                                                                                2.12E-07      1.045    100.00000   18
 19 ++++++++++++++                                                                                2.03E-07               100.00000   19
 20 +                                                                                             0.00E+00               100.00000   20

                                    NUMERICAL RANK =   6
                                    --------------------

                          *  SINGULAR VALUE TRUNCATION OCCURRED AT ORDER =   6  *


INPUT (REFERENCE) COORDINATE CODES:
-----------------------------------
  IC NO.     COORDINATE CODE       MEAS. NO.
    1              1X+                1


* NOTE: FMIN =     0.0000, SF =   100.0000, N1 =  1, ISTRIP =  1.

  THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN       0.0000 &     50.0000 HZ


IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):
```

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%		EMACS >= 80% INPUT (1)	OUTPUT (30)		MPC-W	MPC-U	PRC		ARATIO	RECIP-PROCITY	MSR,%
1	3	35.000**	1.000	(1.000)	:	99.99**	99.99	:	1	30	:	100.00	100.00	1000	:	0.305	:-999.0	54.0
2	1	15.000**	1.000	(1.000)	:	99.99**	99.99	:	1	30	:	100.00	100.00	1000	:	0.601	:-999.0	51.1
3	2	25.010**	1.000	(1.000)	:	99.86**	99.86	:	1	30	:	100.00	100.00	1000	:	0.428	:-999.0	67.3

IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%		EMACS >= 80% INPUT (1)	OUTPUT (30)		MPC-W	MPC-U	PRC		ARATIO	RECIP-PROCITY	MSR,%
1	3	35.000**	1.000	(1.000)	:	99.99**	99.99	:	1	30	:	100.00	100.00	1000	:	0.305	:-999.0	54.0
2	2	25.010**	1.000	(1.000)	:	99.86**	99.86	:	1	30	:	100.00	100.00	1000	:	0.428	:-999.0	67.3
3	1	15.000**	1.000	(1.000)	:	99.99**	99.99	:	1	30	:	100.00	100.00	1000	:	0.601	:-999.0	51.1

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%		EMACS >= 80% INPUT (1)	OUTPUT (30)		MPC-W	MPC-U	PRC		ARATIO	RECIP-PROCITY	MSR,%
1	1	15.000**	1.000	(1.000)	:	99.99**	99.99	:	1	30	:	100.00	100.00	1000	:	0.601	:-999.0	51.1
2	2	25.010**	1.000	(1.000)	:	99.86**	99.86	:	1	30	:	100.00	100.00	1000	:	0.428	:-999.0	67.3
3	3	35.000**	1.000	(1.000)	:	99.99**	99.99	:	1	30	:	100.00	100.00	1000	:	0.305	:-999.0	54.0

```
VAX EXECUTION STATISTICS:
-------------------------

COMPUTER NODENAME AND TYPE:  SDBRP,  VAXstation 3100/GPX

ELAPSED:     0 00:00:12.58  CPU: 0:00:08.86  BUFIO: 52  DIRIO: 88  FAULTS: 945

START DATE/TIME:  20-APR-1994 10:40
  END DATE/TIME:  20-APR-1994 10:41
```

10.11 Example Problem EX011

This example shows the numerical stability of ERA due to the use of singular value decomposition. The generalized Hankel matrix is purposely made singular by duplicating a set of data (2 of the 3 data sets are identical). The Hankel matrix size is 150 rows by 60 columns. The singular values show the numerical rank of the matrix to be 40 rather than 60 because of the duplicated data set. Nonetheless, ERA identifies all 4 modes accurately.

In practice, a singular Hankel matrix would also be obtained if 1 or more response measurements are accidentally repeated in the ERA analysis. This may occur because of the significant amount of data handling required in large modal tests. Singularity may also be caused by 2 or more measurements being too closely spaced on the structure.

Program MIMO adds a low level of noise (0.1%) to the data to illustrate that this singularity occurs even with noisy data. Noise normally causes the Hankel matrix to be of full rank regardless of the number of modes present.

The analysis parameter NOFATL(49) = 1 (see Chapter 6) in Field 4 of the User Input file bypasses the fatal error that occurs if a Tape1 file name is duplicated in Field 2. Appendix C lists all ERA fatal and warning error messages.

Here is a listing of file EX011.COM:

```
$! EX011. ILLUSTRATE NUMERICAL STABILITY WITH SINGULAR HANKEL MATRIX
$!        DUE TO 2 IDENTICAL INPUTS (DATA SETS)
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO PROGRAM
$!
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
$!
$ SET NOVERIFY
$!
$ MIMO
ERAEX11.OUT
 &MIMOIN
 T1NAMS='T1EX11_IC1','T1EX11_IC2'
 PNOISE = 0.1
 NIC = 2, INLOC = 7,25
 NST = 30
 NTIM = 1024
 SF = 100.
 NMODES = 4
 FREQ = 10.0, 15.0, 20.0, 25.0
 ZETAP  = 4*1.0
 AMODES = 4*1.0
 NPTMSR = 43
 &END
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX11.ERA []
$ @ERA EX11
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX11.ERA:

```
$!  EX11.ERA:  EXAMPLE #11
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
```

```
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX11
$!
$ INPUT1:=EX11_IC1
$ INPUT2:=EX11_IC2
$ INPUT3:=EX11_IC1
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=60/
S/MRH=/MRH=150/
S/MIC=/MIC=3/
S/MST=/MST=30/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                       OF AVAILABLE PARAMETERS]
$!
 SF=100,NOFATL(49)=1
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!             [ALWAYS USE EXACTLY 5 LINES]
$!
SHOW NUMERICAL STABILITY WITH 2 IDENTICAL INPUTS (DATA SETS)
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX11:  EXAMPLE #11
```

File 50EX11.LIS

```
* * * ERA -- VERSION 931216 * * *

SHOW NUMERICAL STABILITY WITH 2 IDENTICAL INPUTS (DATA SETS)
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX11:  EXAMPLE #11


TAPE1 FILE NAMES:
-----------------
   1. []T1EX11_IC1.DAT
   2. []T1EX11_IC2.DAT
   3. []T1EX11_IC1.DAT

                                                                        DEFAULT
ANALYSIS PARAMETERS:                                                     VALUE
--------------------
```

```
                (MAX)                                                                                                  -------
 NCH ....... 60 (   60)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                                MCH
 NRH ....... 150 (  150)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                               MRH
 NIC .......  3 (    3)  - NO. OF INITIAL CONDITIONS (INPUTS)                                                            MIC
 NST ....... 30 (   30)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                                   MST
*NTIM ...... 43 ( 1024)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)                  -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                               -
*WINDOW ....     0.420    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                                    -
 FMIN ......     0.000    - FMIN OF DATA (FOR "ZOOMED" DATA)                                                          0.0

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                      -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                      -
 IORFIR .... 50           - ORDER OF BANDPASS FIR FILTER                                                              50

 NSFRST ....  1           - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                             1
 NSFLAG() ..              - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST (CAN BE SELECTED USING KEYDTA=...]      ALL 1
         1111111111 1111111111 1111111111
*NSTBOT .... 30           - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                      NST

 NGENTH ....  0           - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)  0
*NSTDTA .... 30           - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                               -

 N1 ........  1           - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                            1
 N2 ........  1           - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                                1
 N3 ........  1           - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                                1
 N2LAST .... 10           - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                        10
 N3LAST .... 10           - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                        10

 NSKIP .....  0           - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                     0
 ISTRIP ....  1           - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                     1
 ICAS85 ....  1           - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                              1
 DATABW .... -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1  -

 MODELC ....  0           - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 MODELD ....  0           - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 NOAD79 ....  0           - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)     0

*RNKTL0 .... 9.63E-06     - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)          SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....-999          - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")                        -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  9.63E-06    - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                               RNKTL0
 2. MXFLAG .  0           - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                    0
 3. POFVAR .  99.9990     - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                             99.999
 4. MXORDR .  45          - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                      0.75 * MIN(NRH,NCH)

 NUMRNK ....  0           -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BYPASSING CRITERIA 1-4 ABOVE    0

 MIDOPT ....  0           - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]               0

 ITAPE(50) .  1           - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                            1
 ITAPE(51) .  0           - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                                0
 ITAPE(55) .  0           - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                    0
 ITAPE(79) .  0           - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                          0
  MXALL ....  0           -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                            0
  MXHANK ...  0           -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                          0
  MXPDQT ...  0           -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                              0
  MXMTM ....  0           -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT           0
  MXMOMC ...  0           -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                           0
  MXDATA ...  0           -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                            0
   MXDNTM ..-999          -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79      MTIM
   MXDNSF ..  1           -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                          1
   MXDNSL .. 30           -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                        NST
   MXDNIF ..  1           -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                          1
   MXDNIL ..  3           -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                        NIC
 ITAPE(80) .  0           - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...  0           - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80          0
 ITAPE(85) .  1           - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85     1
 ITAPE(88) .  0           - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                        0
 ITYDTA .... 3            - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                      3
 MSSCAL .... 2            - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES     2
 IREFTU .... 0            - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0) 0
 T55CMI ....    1.0       - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                  1.0
 T88CMI ....    1.0       - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                  1.0

 MSTO50 .... 0            - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                   0
 MSPP50 .... 1            - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)             1

 LOOPOP .... 0            - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                0
  PAR(1) ... -999.00      -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                    -
  PAR(2) ... -999.00      -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                    -
  PAR(3) ... -999.00      -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                    -
  PAR(4) ... -999.00      -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                    -
  PAR(5) ... -999.00      -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                    -
*NCASES .... 1            - NO. OF CONSECUTIVE CASES TO RUN                                                            -
                                                                                                                       1

 IPREMC .... 0            - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                   0
 IPRHRS .... 0            - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH  0
 IPRPDQ .... 0            - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                            0
```

```
 IPRABC ....   0          - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                          0
 IPREVS ....   0          - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                              0
 IPRREV ....   0          - IF IPRREV=1, PRINT TIME CONSTANTS & INITIAL AMPS OF REAL EIGENVALUES ON TAPE50                0
 IPRDTA ....   0          - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                         0
 IPRPAR ....   0          - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                         0
 MSRTOT ....   0          - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                              0

 IOMAC .....   0          - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1              0
 ------------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ------------------------------------------------------------------


EX11:  EXAMPLE #11

CASE NO.   1:
------------

CCODE FOR REF.  1 = CCODE FOR REF.  3



-------------------------------------------------------------------------------------------------------------------------------
*  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * *

* * * FATAL ERROR NO. 49 IN ERA * * *

TWO INPUT (REFERENCE) COORDINATE CODES ARE THE SAME.


*  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * *
-------------------------------------------------------------------------------------------------------------------------------


* NOFATL( 49) = 1.  FATAL ERROR IS IGNORED *


IN CASE NO.    1 :

-------------------------------------------------------------------------------------------------------------------------------
* WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE *

* * * WARNING NO. 11 IN ERA * * *

A RATIO BETWEEN CONSECUTIVE SINGULAR VALUES >= 20 WAS DETECTED. MXFLAG WAS CHANGED TO 1 AND ALL OTHER S.V. CUTOFF
CRITERIA WERE DISABLED.


* WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE *
-------------------------------------------------------------------------------------------------------------------------------


D(1) =   3.34030E+01

                                                                                                                 CUMULATIVE
                                                                                                                    % OF
SINGULAR VALUES, D():                                                                  D(N)/D(1)  D(N)/D(N+1)  VARIANCE   N

  1 ********************************************************************************************** 1.00E+00      1.108   27.08195   1
  2 *********************************************************************************************  9.03E-01      1.233   49.15875   2
  3 ******************************************************************************************     7.33E-01      1.134   63.69186   3
  4 ***************************************************************************************        6.46E-01      1.058   74.98997   4
  5 *************************************************************************************          6.10E-01      1.177   85.08070   5
  6 ********************************************************************************             5.19E-01      1.252   92.36901   6
  7 *****************************************************************************                4.14E-01      1.248   97.01753   7
  8 ************************************************************************************           3.32E-01    579.708*  99.99993   8
  9 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  5.72E-04      1.043   99.99994   9
 10 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  5.49E-04      1.019   99.99995  10
 11 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  5.39E-04      1.044   99.99996  11
 12 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  5.16E-04      1.047   99.99998  12
 13 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  4.93E-04      1.033   99.99998  13
 14 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  4.77E-04      1.054  100.00000  14
 15 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++    4.53E-04      1.027  100.00000  15
 16 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++    4.41E-04      1.039  100.00000  16
 17 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++    4.24E-04      1.021  100.00000  17
 18 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++    4.16E-04      1.051  100.00000  18
 19 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++    3.96E-04      1.021  100.00000  19
 20 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++    3.87E-04      1.040  100.00000  20
 21 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++      3.73E-04      1.023  100.00000  21
 22 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++      3.64E-04      1.022  100.00000  22
 23 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++      3.56E-04      1.019  100.00000  23
 24 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++      3.50E-04      1.004  100.00000  24
 25 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++      3.48E-04      1.028  100.00000  25
```

```
26 ++++++
```

```
  2   3    20.000**    1.000   ( 1.000)  :   99.80**   99.80  :      3     30  :  100.00  100.00  1000  :  0.597  : 100.0   56.7
-----------------------------------------------------------------------------------------------------------------------------------
  3   4    25.000**    0.999   ( 0.997)  :   99.78**   99.78  :      3     30  :  100.00  100.00  1000  :  0.526  : 100.0   27.6
-----------------------------------------------------------------------------------------------------------------------------------
  4   1    10.000**    0.996   ( 0.999)  :   99.79**   99.79  :      3     30  :  100.00  100.00  1000  :  0.773  : 100.0   43.2


IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):
-------------------------------------------------

    E.V.  FREQUENCY,  DAMPING                          AVG.     EMACS >= 80%                                                  RECIP-
     NO.    HERTZ     FACTOR, % (ZETA2,%)      CMI,%    EMAC,%    INPUT  OUTPUT     MPC-W   MPC-U   PRC    ARATIO   PROCITY  MSR,%
                                                                   (   3) (  30)
-----------------------------------------------------------------------------------------------------------------------------------
  1   1    10.000**    0.996   ( 0.999)  :   99.79**   99.79  :      3     30  :  100.00  100.00  1000  :  0.773  : 100.0   43.2
-----------------------------------------------------------------------------------------------------------------------------------
  2   2    15.000**    0.999   ( 1.002)  :   99.83**   99.83  :      3     30  :  100.00  100.00  1000  :  0.679  : 100.0   64.3
-----------------------------------------------------------------------------------------------------------------------------------
  3   3    20.000**    1.000   ( 1.000)  :   99.80**   99.80  :      3     30  :  100.00  100.00  1000  :  0.597  : 100.0   56.7
-----------------------------------------------------------------------------------------------------------------------------------
  4   4    25.000**    0.999   ( 0.997)  :   99.78**   99.78  :      3     30  :  100.00  100.00  1000  :  0.526  : 100.0   27.6


VAX EXECUTION STATISTICS:
------------------------

COMPUTER NODENAME AND TYPE:  SDBHR,  VAXstation 3100-M76/GPX

ELAPSED:    0 00:00:11.89  CPU: 0:00:07.05  BUFIO: 74  DIRIO: 124  FAULTS: 1122

START DATE/TIME:  24-MAR-1994 11:21
  END DATE/TIME:  24-MAR-1994 11:21
```

10.12 Example Problem EX012

This example demonstrates the accurate identification of 2 closely spaced modes using less than 1 cycle of data of each. The modes are at 0.500 and 0.501 Hz. The ERA analysis uses 25 data samples at a sampling frequency of 100 Hz corresponding to a data length of 0.25 seconds. **This is only 1/8 cycle of response.** Also, note that the data length of 0.25 seconds is much less than the beat time of 1000 seconds (1/delta freq.) between the 2 modes. ERA identifies both modes accurately as shown at the end of the Tape50 output file listed below.

With ideal data (no distortion), ERA requires only 4 data samples per mode, ref. Example Problem EX001 (Section 10.1). In practice, a minimum of 3 cycles of the lowest-frequency mode is recommended.

Here is a listing of file EX012.COM:

```
$! EX012. SHOW ACCURATE I.D. OF 2 CLOSELY SPACED MODES
$!        USING LESS THAN 1 CYCLE OF DATA FOR EACH.
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO PROGRAM
$!
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
$!
$ MIMO
ERAEX12.OUT
```

```
 &MIMOIN
 T1NAMS='T1EX12_IC1','T1EX12_IC2'
 PNOISE = 0
 NIC = 2, INLOC = 7,25
 NST = 30
 NTIM = 25
 SF = 100.
 NMODES = 2
 FREQ = 0.5, 0.501
 ZETAP  = 2*1.0
 AMODES = 2*1.0
 NPTMSR = 25
 &END
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX12.ERA []
$ @ERA EX12
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX12.ERA:

```
$!  EX12.ERA:  EXAMPLE #12
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX12
$!
$ INPUT1:=EX12_IC1
$ INPUT2:=EX12_IC2
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=10/
S/MRH=/MRH=60/
S/MIC=/MIC=2/
S/MST=/MST=30/
S/MTIM=/MTIM=25/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
```

```
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                       OF AVAILABLE PARAMETERS]
$!
 SF=100
 NUMRNK=1,F1=0.5,NOFATL(55)=1
 MSTO50=1
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!              [ALWAYS USE EXACTLY 5 LINES]
$!
SHOW I.D. OF 2 CLOSE MODES USING LESS THAN 1 CYCLE OF DATA
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX12:  EXAMPLE #12
```

File 50EX12.LIS

```
* * * ERA -- VERSION 931216 * * *


SHOW I.D. OF 2 CLOSE MODES USING LESS THAN 1 CYCLE OF DATA
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX12:  EXAMPLE #12


TAPE1 FILE NAMES:
----------------
   1. []T1EX12_IC1.DAT
   2. []T1EX12_IC2.DAT


WINDOW, F1, CYCLES =      0.240     0.500     0.120


-------------------------------------------------------------------------------------------------------------------
*  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * *

* * * FATAL ERROR NO. 55 IN ERA * * *

LESS THAN 1 CYCLE OF LOWEST-FREQ. MODE WILL BE USED WITH THE SELECTED ANALYSIS PARAMETERS.  MODIFY ANALYSIS PARAMETERS, OR
RERUN WITH NOFATL(55)=1 TO BYPASS THIS FATAL ERROR.  (SEE SPECIFIC VALUES LISTED ABOVE.)


*  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * *
-------------------------------------------------------------------------------------------------------------------


* NOFATL( 55) = 1.  FATAL ERROR IS IGNORED *


IN CASE NO.    1 :


-------------------------------------------------------------------------------------------------------------------
* WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE *

* * * WARNING NO. 15 IN ERA * * *

LESS THAN 2 CYCLES OF LOWEST-FREQ. MODE IS BEING USED IN THIS ANALYSIS.  AT LEAST 2 CYCLES SHOULD BE USED IN MOST
SITUATIONS.


* WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE * * WARNING MESSAGE *
-------------------------------------------------------------------------------------------------------------------
```

```
ANALYSIS PARAMETERS:                                                                                                    DEFAULT
-------------------                                                                                                     VALUE
                  (MAX)                                                                                                 -------
 NCH .......  10 (   10)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                               MCH
 NRH .......  60 (   60)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                               MRH
 NIC .......   2 (    2)  - NO. OF INITIAL CONDITIONS (INPUTS)                                                          MIC
 NST .......  30 (   30)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                                 MST
*NTIM ......  25 (   25)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)              -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                             -

*CYCLES ....     0.120    - NO. OF CYCLES OF LOWEST-FREQ. MODE, BASED ON USER PARAMETER F1 =   0.50 HZ               -
*WINDOW ....     0.240    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                                 -
 FMIN ......     0.000    - FMIN OF DATA (FOR "ZOOMED" DATA)                                                         0.0

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                   -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                                   -
 IORFIR ....  50          - ORDER OF BANDPASS FIR FILTER                                                             50

 NSFRST ....  1           - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                           1
 NSFLAG() ..              - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]      ALL 1
          1111111111 1111111111 1111111111
*NSTBOT ....  30          - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                     NST

 NGENTH ....  0           - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)  0
*NSTDTA ....  30          - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                              -

 N1 ........  1           - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                           1
 N2 ........  1           - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                               1
 N3 ........  1           - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                               1
 N2LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                        10
 N3LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                        10

 NSKIP .....  0           - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                   0
 ISTRIP ....  1           - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                   1
 ICAS85 ....  1           - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                             1
 DATABW ....  -999.000    - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1  -

 MODELC ....  0           - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 MODELD ....  0           - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 NOAD79 ....  0           - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)    0

*RNKTL0 ....  3.63E-06    - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)          SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....-999          - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")                      -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  3.63E-06    - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                               RNKTL0
 2. MXFLAG .  0           - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                  0
 3. POFVAR . 101.0000     - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                            99.999
 4. MXORDR .  10          - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                    0.75 * MIN(NRH,NCH)

 NUMRNK ....  1           -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BYPASSING CRITERIA 1-4 ABOVE  0

 MIDOPT ....  0           - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]              0

 ITAPE(50) .  1           - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                          1
 ITAPE(51) .  0           - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                              0
 ITAPE(55) .  0           - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                  0
 ITAPE(79) .  0           - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                        0
  MXALL ....  0           -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                          0
  MXHANK ...  0           -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                        0
  MXPDQT ...  0           -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                            0
  MXMTM ....  0           -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT         0
  MXMOMC ...  0           -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                         0
  MXDATA ...  0           -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                          0
   MXDNTM ..-999          -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79      MTIM
   MXDNSF ..  1           -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                        1
   MXDNSL ..  30          -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                        NST
   MXDNIF ..  1           -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                        1
   MXDNIL ..  2           -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                        NIC
 ITAPE(80) .  0           - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...  0           - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80        0
 ITAPE(85) .  1           - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85   1
 ITAPE(88) .  0           - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                      0
 ITYDTA ....  3           - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                    3
 MSSCAL ....  2           - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES   2
 IREFTU ....  0           - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)  0
 T55CMI ....    1.0       - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                  1.0
 T88CMI ....    1.0       - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                  1.0

 MSTO50 ....  1           - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                 0
 MSPP50 ....  1           - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)           1

 LOOPOP ....  0           - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS              0
  PAR(1) ... -999.00      -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                  -
  PAR(2) ... -999.00      -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                  -
  PAR(3) ... -999.00      -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                  -
  PAR(4) ... -999.00      -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                  -
  PAR(5) ... -999.00      -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                  -
```

```
*NCASES ....   1          - NO. OF CONSECUTIVE CASES TO RUN                                                                  1
IPREMC ....   0          - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                         0
IPRHRS ....   0          - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH  0
IPRPDQ ....   0          - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                                  0
IPRABC ....   0          - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                              0
IPREVS ....   0          - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                                  0
IPRREV ....   0          - IF IPRREV=1, PRINT TIME CONSTANTS & INITIAL AMPS OF REAL EIGENVALUES ON TAPE50                   0
IPRDTA ....   0          - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                             0
IPRPAR ....   0          - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                             0
MSRTOT ....   0          - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                                  0
IOMAC .....   0          - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1                  0
-----------------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
-----------------------------------------------------------------------
```

EX12: EXAMPLE #12

CASE NO. 1:

D(1) = 5.53340E+00

SINGULAR VALUES, D():

```
                                                                                                                  D(N)/D(1)   D(N)/D(N+1)  CUMULATIVE % OF VARIANCE   N
 1 ************************************************************************************************  1.00E+00      1.591     68.64078   1
 2 ************************************************************************************************  6.29E-01      2.987     95.75908   2
 3 ************************************************************************************************  2.10E-01      1.591     98.79946   3
 4 ************************************************************************************************  1.32E-01*                100.00000   4
 5 X                                                                                                 0.00E+00                100.00000   5
 6 +                                                                                                 0.00E+00                100.00000   6
 7 +                                                                                                 0.00E+00                100.00000   7
 8 +                                                                                                 0.00E+00                100.00000   8
 9 +                                                                                                 0.00E+00                100.00000   9
10 +                                                                                                 0.00E+00                100.00000  10
```

NUMERICAL RANK = 4

* SINGULAR VALUE TRUNCATION OCCURRED AT ORDER = 4 *

INPUT (REFERENCE) COORDINATE CODES:

IC NO.	COORDINATE CODE	MEAS. NO.
1	7X+	7
2	25X+	25

* NOTE: FMIN = 0.0000, SF = 100.0000, N1 = 1, ISTRIP = 1.

THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN 0.0000 & 50.0000 HZ

IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):

	E.V. NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (2)	OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	2	0.501**	1.001	(1.000)	100.00**	100.00	2	30	100.00	100.00	999	0.993	100.0	101.0
2	1	0.500**	1.001	(1.000)	100.00**	100.00	2	30	100.00	100.00	999	0.993	100.0	75.7

IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):

	E.V. NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (2)	OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	2	0.501**	1.001	(1.000)	100.00**	100.00	2	30	100.00	100.00	999	0.993	100.0	101.0
2	1	0.500**	1.001	(1.000)	100.00**	100.00	2	30	100.00	100.00	999	0.993	100.0	75.7

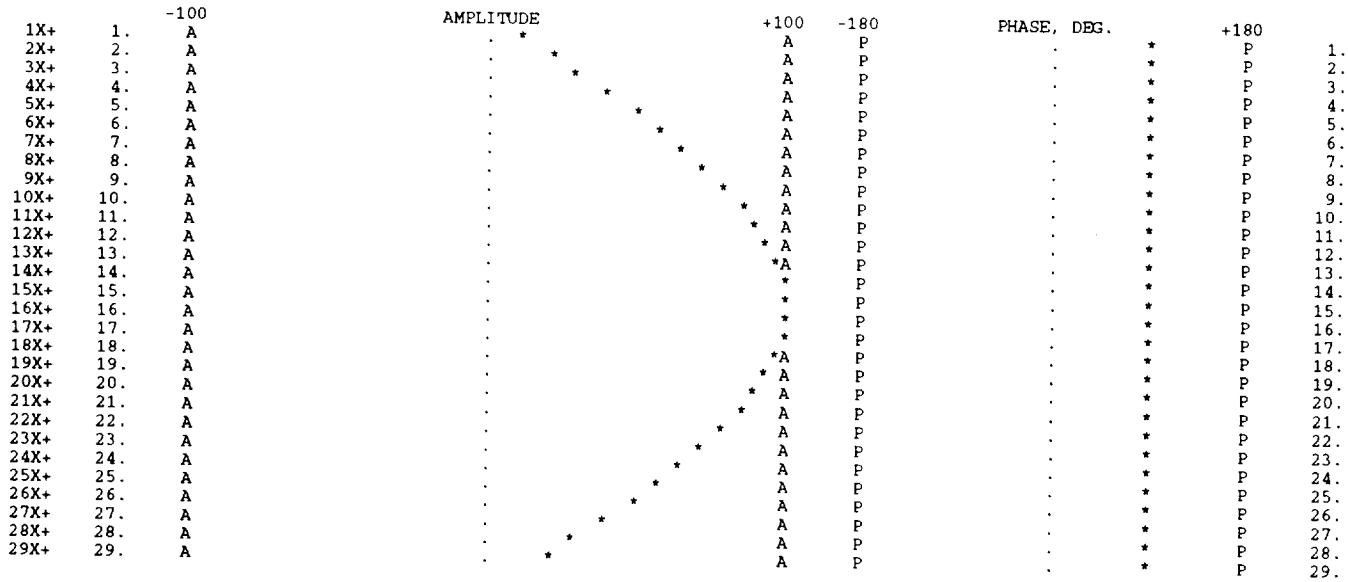
C-5

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (2)	OUTPUT (30)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	0.500**	1.001	(1.000)	100.00**	100.00	2	30	100.00	100.00	999	0.993	100.0	75.7
2	2	0.501**	1.001	(1.000)	100.00**	100.00	2	30	100.00	100.00	999	0.993	100.0	101.0

EIGENVALUE NO. 1 FREQUENCY = 0.500 HZ

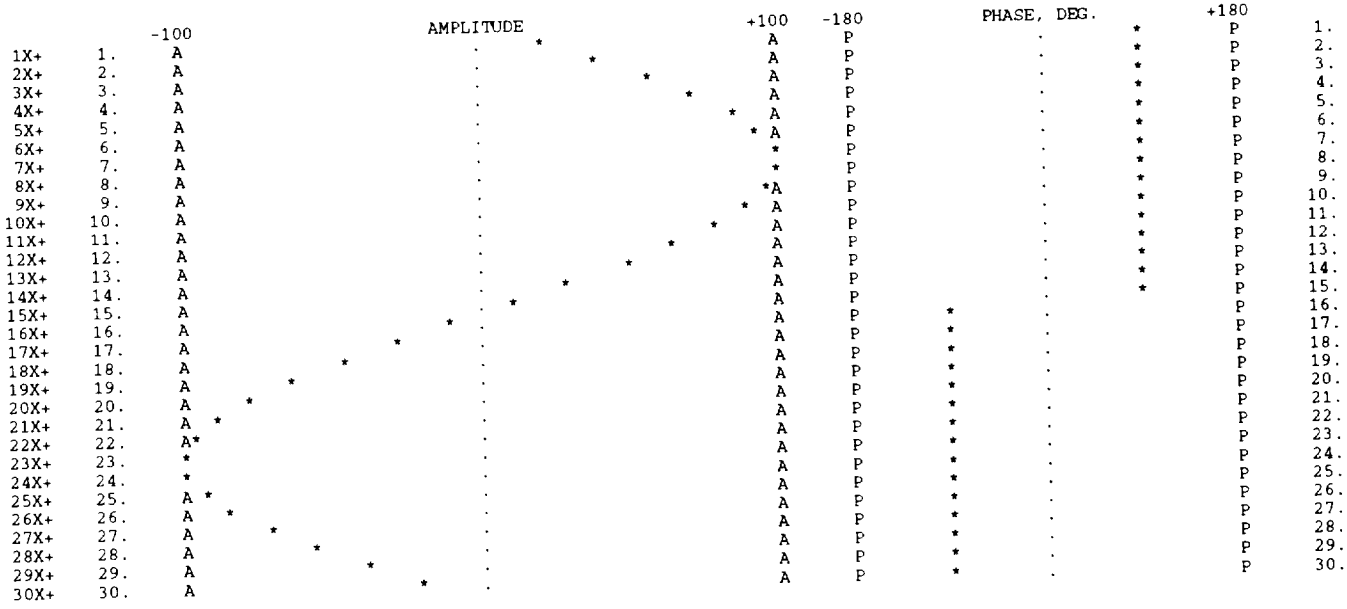
EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE		INITIAL PHYSICAL AMPLITUDES IC # 1	7X+	IC # 2	25X+
1	0.500**	1.001	1X+	1	10.13	90.2	6.5370E-02	-89.9	5.8321E-02	-89.8
			2X+	2	20.16	90.2	1.3007E-01	-89.9	1.1604E-01	-89.8
			3X+	3	29.98	90.1	1.9343E-01	-89.9	1.7257E-01	-89.8
			4X+	4	39.49	90.1	2.5481E-01	-89.9	2.2733E-01	-89.8
			5X+	5	48.60	90.1	3.1357E-01	-89.9	2.7976E-01	-89.8
			6X+	6	57.21	90.1	3.6911E-01	-90.0	3.2931E-01	-89.8
			7X+	7	65.23	90.1	4.2086E-01	-90.0	3.7548E-01	-89.8
			8X+	8	72.58	90.1	4.6829E-01	-90.0	4.1780E-01	-89.8
			9X+	9	79.19	90.1	5.1092E-01	-90.0	4.5583E-01	-89.8
			10X+	10	84.98	90.1	5.4830E-01	-90.0	4.8918E-01	-89.8
			11X+	11	89.90	90.1	5.8005E-01	-90.0	5.1751E-01	-89.8
			12X+	12	93.90	90.1	6.0585E-01	-90.0	5.4052E-01	-89.9
			13X+	13	96.94	90.0	6.2543E-01	-90.0	5.5799E-01	-89.9
			14X+	14	98.98	90.0	6.3859E-01	-90.1	5.6974E-01	-89.9
			15X+	15	100.00	90.0	6.4520E-01	-90.1	5.7563E-01	-89.9
			16X+	16	100.00	90.0	6.4519E-01	-90.1	5.7562E-01	-89.9
			17X+	17	98.97	90.0	6.3855E-01	-90.1	5.6970E-01	-89.9
			18X+	18	96.93	90.0	6.2537E-01	-90.1	5.5794E-01	-90.0
			19X+	19	93.89	89.9	6.0577E-01	-90.1	5.4045E-01	-90.0
			20X+	20	89.89	89.9	5.7995E-01	-90.1	5.1742E-01	-90.0
			21X+	21	84.96	89.9	5.4819E-01	-90.2	4.8908E-01	-90.0
			22X+	22	79.17	89.9	5.1080E-01	-90.2	4.5572E-01	-90.0
			23X+	23	72.56	89.9	4.6817E-01	-90.2	4.1769E-01	-90.0
			24X+	24	65.21	89.9	4.2074E-01	-90.2	3.7538E-01	-90.0
			25X+	25	57.19	89.9	3.6900E-01	-90.2	3.2921E-01	-90.0
			26X+	26	48.58	89.9	3.1346E-01	-90.2	2.7967E-01	-90.0
			27X+	27	39.48	89.9	2.5472E-01	-90.2	2.2725E-01	-90.1
			28X+	28	29.97	89.9	1.9336E-01	-90.2	1.7251E-01	-90.1
			29X+	29	20.15	89.8	1.3002E-01	-90.2	1.1600E-01	-90.1
			30X+	30	10.13	89.8	6.5345E-02	-90.2	5.8299E-02	-90.1
			NORMALIZED MODAL PARTICIPATION FACTOR(S):				100.00	-0.1	89.22	0.1



30X+ 30. A * A P . * P 30.

EIGENVALUE NO. 2 FREQUENCY = 0.501 HZ

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE		INITIAL PHYSICAL AMPLITUDES IC # 1	7X+	IC # 2	25X+
2	0.501**	1.001	1X+	1	20.13	90.0	1.9951E-01	-90.0	1.8929E-01	90.1
			2X+	2	39.44	90.0	3.9086E-01	-90.0	3.7086E-01	90.1
			3X+	3	57.14	90.0	5.6625E-01	-90.0	5.3726E-01	90.1
			4X+	4	72.50	90.0	7.1851E-01	-90.0	6.8172E-01	90.1
			5X+	5	84.90	90.0	8.4141E-01	-90.0	7.9834E-01	90.1
			6X+	6	93.84	90.0	9.2995E-01	-90.0	8.8234E-01	90.1
			7X+	7	98.94	90.0	9.8050E-01	-90.0	9.3031E-01	90.1
			8X+	8	100.00	90.0	9.9103E-01	-90.0	9.4029E-01	90.1
			9X+	9	96.98	90.0	9.6109E-01	-90.0	9.1189E-01	90.1
			10X+	10	90.00	90.0	8.9195E-01	-90.0	8.4628E-01	90.1
			11X+	11	79.35	90.1	7.8642E-01	-90.0	7.4616E-01	90.1
			12X+	12	65.47	90.1	6.4885E-01	-90.0	6.1563E-01	90.1
			13X+	13	48.93	90.1	4.8486E-01	-89.9	4.6004E-01	90.2
			14X+	14	30.39	90.2	3.0119E-01	-89.9	2.8577E-01	90.2
			15X+	15	10.63	90.5	1.0534E-01	-89.6	9.9951E-02	90.5
			16X+	16	9.55	-90.6	9.4657E-02	89.4	8.9811E-02	-90.5
			17X+	17	29.32	-90.2	2.9061E-01	89.8	2.7573E-01	-90.1
			18X+	18	47.88	-90.1	4.7450E-01	89.8	4.5021E-01	-90.1
			19X+	19	64.46	-90.1	6.3881E-01	89.9	6.0611E-01	-90.0
			20X+	20	78.38	-90.1	7.7681E-01	89.9	7.3704E-01	-90.0
			21X+	21	89.09	-90.1	8.8286E-01	89.9	8.3767E-01	-90.0
			22X+	22	96.13	-90.0	9.5263E-01	89.9	9.0386E-01	-90.0
			23X+	23	99.22	-90.0	9.8327E-01	89.9	9.3293E-01	-90.0
			24X+	24	98.23	-90.0	9.7353E-01	89.9	9.2369E-01	-90.0
			25X+	25	93.22	-90.0	9.2383E-01	89.9	8.7654E-01	-90.0
			26X+	26	84.38	-90.0	8.3622E-01	89.9	7.9341E-01	-90.0
			27X+	27	72.08	-90.0	7.1429E-01	89.9	6.7772E-01	-90.0
			28X+	28	56.81	-90.0	5.6305E-01	89.9	5.3422E-01	-90.0
			29X+	29	39.22	-90.0	3.8871E-01	89.9	3.6881E-01	-90.0
			30X+	30	20.02	-90.0	1.9843E-01	89.9	1.8827E-01	-90.0
			NORMALIZED MODAL PARTICIPATION FACTOR(S):				100.00	-0.1	94.88	0.0



VAX EXECUTION STATISTICS:

COMPUTER NODENAME AND TYPE: SDBHR, VAXstation 3100-M76/GPX

ELAPSED: 0 00:00:07.67 CPU: 0:00:01.86 BUFIO: 69 DIRIO: 137 FAULTS: 864

START DATE/TIME: 24-MAR-1994 14:01
END DATE/TIME: 24-MAR-1994 14:01

10.13 Example Problem EX013

The Extended Modal Amplitude Coherence (EMAC) measures the temporal consistency of the identification results (ref. Section 2.6.2). EMAC is computed using the identified modal parameters. Mode shape and modal participation components for data at $t = 0$ are compared with corresponding components for data at $t = T_o$ (for outputs) or $t = T_I$ (for inputs) located in the final block row and final block column, respectively, of the modal observability matrix (MOM):

$$\overline{V} = PD^{1/2}\Psi$$

and modal controllability matrix (MCM):

$$\overline{W} = \Psi^{-1}D^{1/2}Q^T .$$

Data in the corresponding final block row (block row r) and final block column (block column s) of the generalized Hankel matrices, Eq. 2-17, are shifted by 10 time samples (by default) from the previous block row and block column, providing an extension of the primary data analysis window.

Block rows 2 through $r-1$ and block columns 2 through $s-1$ of the Hankel matrices are shifted by 1 time sample (by default) from the previous block row and column, and block row r and block column s are shifted by 10 time samples (by default) from the previous block row and column. In software terminology, block rows 2 through $r-1$ and block columns 2 through $s-1$ are shifted by N2 and N3 time samples, respectively. Block row r and block column s are shifted by N2LAST and N3LAST time samples, respectively. The default value of N2 and N3 is 1. The default value of N2LAST and N3LAST is 10. (Appendix K and Chapter 6 contain additional information.)

The default value of 10 for N2LAST and N3LAST is empirical. It was selected based on observed effectiveness with many different data sets. Users may vary N2LAST and/or N3LAST by including these parameters in Field 4 of the User Input file. As N2LAST and/or N3LAST is reduced from a value of 10, EMAC increases.[228] As it is reduced from a value of 10, EMAC decreases.

[228]Example Problem EX015 (Section 10.15) discusses the undesirable situation of **all** EMAC values being 100% under certain circumstances. (This never occurs using the default values of the analysis parameters.)

This examples shows the variation of EMAC for N2LAST = N3LAST values ranging from 1 to 50. Field 4 of the User Input file includes the following statement to cause ERA to automatically increment N2LAST and N3LAST over these values:

```
LOOPOP=9,PAR=1,50,1
```

Figure 10-5 shows the results, plotted using GO Input file G15_4_LO9_EX13.COM.

Here is a listing of file EX013.COM:

```
$! EX013. SHOW VARIATION OF EMAC RESULTS VS. N2LAST AND N3LAST.
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO PROGRAM
$!
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
$!
$ MIMO
ERAEX13.OUT
 &MIMOIN
 T1NAMS='T1EX13'
 PNOISE = 0.2
 NIC = 1, INLOC = 1
 NST = 1
 NTIM = 1024
 SF = 100.
 NMODES = 1
 FREQ = 20.0
 ZETAP  = 1.0
 AMODES = 1.0
 NPTMSR = 43
 &END
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX13.ERA []
$ @ERA EX13
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX13.ERA:

```
$!  EX13.ERA:  EXAMPLE #13
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
```

```
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX13
$!
$ INPUT1:=EX13
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=10/
S/MRH=/MRH=10/
S/MIC=/MIC=1/
S/MST=/MST=1/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=100
 LOOPOP=9,PAR=1,50,1
 NOFATL(44)=1,NOFATL(45)=1
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!            [ALWAYS USE EXACTLY 5 LINES]
$!
SHOW VARIATION OF EMAC VS. N2LAST AND N3LAST
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX13:  EXAMPLE #13
```

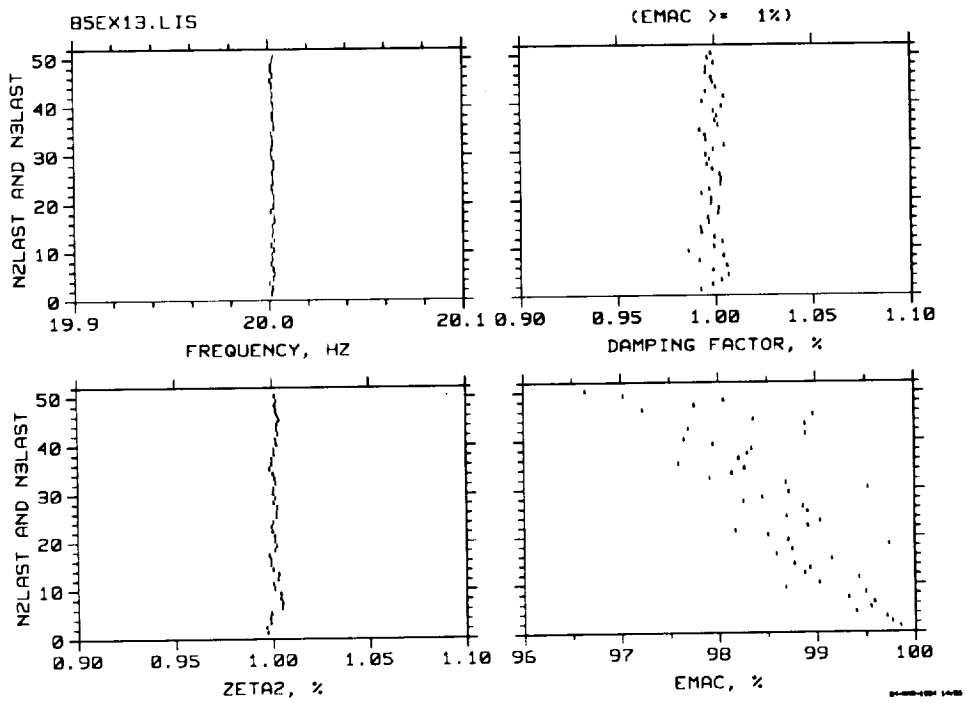


Fig. 10-5. Decreasing EMAC With Increasing N2LAST and N3LAST [G15_4_LO9_EX13.COM]

10.14 Example Problem EX014

Theoretically (with ideal data), analysis parameters NCH and NRH can both be as small as twice the number of modes comprising the data.[229] NCH and NRH are the number of columns and rows, respectively, in the generalized Hankel matrix.

This example reruns test case SISO1 (Section 9.1.1) using a minimum Hankel matrix size of 6 x 6. There are 3 modes having the following frequencies: 10, 15, and 30 Hz. ERA accurately identifies all modal parameters as shown at the end of the Tape50 output file listed below.

Here is a listing of file EX014.COM:

```
$! EX014.  TEST CASE SISO1 WITH MINIMUM HANKEL MATRIX SIZE (6 X 6)
$!
$! CONSTRUCT TAPE1 FILE USING SISO PROGRAM
$!
$ SISO
T1EX14.DAT    TAPE1 FILE TO RECEIVE DATA
```

[229]NCH and NRH are typically specified by selecting MCH and MRH, respectively. See Chapter 6.

```
1024      NTIM
100       SF
10        FREQ. MODE 1 (ENTER 0.0 FOR REAL EIGENVALUE)
1         ZETAP MODE 1
1         AMPL. MODE 1
90        PHSD  MODE 1
Y         MORE MODES ?  Y OR N
15        FREQ. MODE 2
1         ZETAP MODE 2
2         AMPL. MODE 2
-90       PHSD  MODE 2
Y         MORE MODES ?  Y OR N
30        FREQ. MODE 3
2         ZETAP MODE 3
5.1234    AMPL. MODE 3
85.5      PHSD  MODE 3
N         MORE MODES ?  Y OR N
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX14.ERA []
$ @ERA EX14
```

Here is a listing of the ERA User Input file for this problem, EX14.ERA:

```
$! EX14.ERA:  EXAMPLE #14
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX14
$!
$ INPUT1:=EX14
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=6/
S/MRH=/MRH=6/
S/MIC=/MIC=1/
S/MST=/MST=1/
S/MTIM=/MTIM=1024/
$!
```

```
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                        OF AVAILABLE PARAMETERS]
$!
 SF=100,NUMRNK=1
 MIDOPT=1,MSTO50=1,MSPP50=0
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!             [ALWAYS USE EXACTLY 5 LINES]
$!
LINE 1 FOR USER-SUPPLIED JOB DESCRIPTION
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX14: TEST CASE SISO1 W/ MIN. HANKEL MATRIX SIZE
```

File 50EX14.LIS

```
* * * ERA -- VERSION 931216 * * *


LINE 1 FOR USER-SUPPLIED JOB DESCRIPTION
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX14: TEST CASE SISO1 W/ MIN. HANKEL MATRIX SIZE


TAPE1 FILE NAMES:
-----------------
   1. []T1EX14.DAT

ANALYSIS PARAMETERS:                                                                                    DEFAULT
--------------------                                                                                    VALUE
                  (MAX)                                                                                 -------
 NCH .......   6 (    6)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                  MCH
 NRH .......   6 (    6)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                  MRH
 NIC .......   1 (    1)  - NO. OF INITIAL CONDITIONS (INPUTS)                                             MIC
 NST .......   1 (    1)  - NO. OF RESPONSE STATIONS (OUTPUTS)   [ = NGENTH + NSTDTA]                     MST
*NTIM ......  30 ( 1024)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)  -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                  -
*WINDOW ....     0.290    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                       0.0
 FMIN ......     0.000    - FMIN OF DATA (FOR "ZOOMED" DATA)

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                         -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                         -
 IORFIR ....  50          - ORDER OF BANDPASS FIR FILTER                                                   50

 NSFRST ....   1          - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                 1
 NSFLAG() ..               - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]  ALL 1
          1
*NSTBOT ....   1          - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                           NST

 NGENTH ....   0          - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)  0
*NSTDTA ....   1          - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                   -

 N1 ........   1          - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                1
 N2 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                    1
 N3 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                    1
 N2LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)             10
 N3LAST ....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)             10

 NSKIP .....   0          - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION         0
 ISTRIP ....   1          - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.         1
 ICAS85 ....   1          - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                  1
 DATABW ....  -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1  -

 MODELC ....   0          - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 MODELD ....   0          - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79  0
 NOAD79 ....   0          - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)  0

*RNKTL0 ....  5.06E-07    - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)          SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....-999          - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")            -
```

```
IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  5.06E-07    - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                          RNKTL0
 2. MXFLAG .    0         - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                0
 3. POFVAR . 101.0000     - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                      99.999
 4. MXORDR .    6         - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                  0.75 * MIN(NRH,NCH)

 NUMRNK ....    1         -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BYPASSING CRITERIA 1-4 ABOVE   0

 MIDOPT ....    1         - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]               0

 ITAPE(50) .    1         - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50
 ITAPE(51) .    0         - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                            1
 ITAPE(55) .    0         - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                0
 ITAPE(79) .    0         - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                      0
  MXALL ....    0         -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                        0
  MXHANK ...    0         -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                      0
  MXPDQT ...    0         -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                          0
  MXMTM ....    0         -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT       0
  MXMOMC ...    0         -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                       0
  MXDATA ...    0         -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                        0
   MXDNTM ..-999          -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79    MTIM
   MXDNSF ..   1          -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                      1
   MXDNSL ..   1          -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                    NST
   MXDNIF ..   1          -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                      1
   MXDNIL ..   1          -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                    NIC
 ITAPE(80) .   0          - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...   0          - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80      0
 ITAPE(85) .   1          - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85  1
 ITAPE(88) .   0          - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                    0
 ITYDTA ....   3          - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                  3
 MSSCAL ....   2          - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES 2
 IREFTU ....   0          - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)  0
 T55CMI ....     1.0      - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                              1.0
 T88CMI ....     1.0      - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                              1.0

 MSTO50 ....   1          - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)
 MSPP50 ....   0          - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)         0
                                                                                                                   1
 LOOPOP ....   0          - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS
  PAR(1) ... -999.00      -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                0
  PAR(2) ... -999.00      -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                -
  PAR(3) ... -999.00      -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                -
  PAR(4) ... -999.00      -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                -
  PAR(5) ... -999.00      -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                -
*NCASES ....   1          - NO. OF CONSECUTIVE CASES TO RUN                                                        -
                                                                                                                   1
 IPREMC ....   0          - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55
 IPRHRS ....   0          - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH  0
 IPRPDQ ....   0          - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                        0
 IPRABC ....   0          - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                    0
 IPREVS ....   0          - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                        0
 IPRREV ....   0          - IF IPRREV=1, PRINT TIME CONSTANTS & INITIAL AMPS OF REAL EIGENVALUES ON TAPE50          0
 IPRDTA ....   0          - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                   0
 IPRPAR ....   0          - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                   0
 MSRTOT ....   0          - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                        0

 IOMAC .....   0          - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1        0
 ------------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ------------------------------------------------------------------


EX14: TEST CASE SISO1 W/ MIN. HANKEL MATRIX SIZE

CASE NO.    1:
------------

D(1) =   1.35612E+01

SINGULAR VALUES, D():

                                                                                                  CUMULATIVE
                                                                                                    % OF
                                                                          D(N)/D(1)  D(N)/D(N+1)  VARIANCE   N
  1 ********************************************************************************************
  2 ********************************************************************************************  1.00E+00    1.097    48.09014   1
  3 ********************************************************************************************  9.12E-01    2.151    88.07028   2
  4 ************************************************************************                       4.24E-01    1.838    96.71308   3
  5 ************************************************                                               2.31E-01    1.891    99.27252   4
  6 ********************************************                                                 1.22E-01    7.824    99.98831   5
                                                                                                1.56E-02               100.00000   6*


INPUT (REFERENCE) COORDINATE CODES:
-----------------------------------
  IC NO.     COORDINATE CODE       MEAS. NO.
    1              1X+                 1
```

* NOTE: FMIN = 0.0000, SF = 100.0000, N1 = 1, ISTRIP = 1.

THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN 0.0000 & 50.0000 HZ

IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):

	E.V. NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	EMACS >= 80% OUTPUT (1)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	3	30.000**	2.000	(2.000)	100.00**	100.00	1	1	-999.00	-999.00	-999	0.348	-999.0	86.6
2	2	15.000**	1.000	(1.000)	99.98**	99.98	1	1	-999.00	-999.00	-999	0.768	-999.0	40.3
3	1	10.000**	1.001	(1.000)	99.98**	99.98	1	1	-999.00	-999.00	-999	0.839	-999.0	20.6

IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):

	E.V. NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	EMACS >= 80% OUTPUT (1)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	10.000**	1.001	(1.000)	99.98**	99.98	1	1	-999.00	-999.00	-999	0.839	-999.0	20.6
2	2	15.000**	1.000	(1.000)	99.98**	99.98	1	1	-999.00	-999.00	-999	0.768	-999.0	40.3
3	3	30.000**	2.000	(2.000)	100.00**	100.00	1	1	-999.00	-999.00	-999	0.348	-999.0	86.6

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

	E.V. NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)	CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	EMACS >= 80% OUTPUT (1)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	10.000**	1.001	(1.000)	99.98**	99.98	1	1	-999.00	-999.00	-999	0.839	-999.0	20.6
2	2	15.000**	1.000	(1.000)	99.98**	99.98	1	1	-999.00	-999.00	-999	0.768	-999.0	40.3
3	3	30.000**	2.000	(2.000)	100.00**	100.00	1	1	-999.00	-999.00	-999	0.348	-999.0	86.6

EIGENVALUE NO. 1 FREQUENCY = 10.000 HZ

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE		INITIAL PHYSICAL AMPLITUDES IC # 1	1X+
1	10.000**	1.001	1X+	1	100.00	90.0	1.0000E+00	90.0

NORMALIZED MODAL PARTICIPATION FACTOR(S): 100.00 0.0

EIGENVALUE NO. 2 FREQUENCY = 15.000 HZ

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE		INITIAL PHYSICAL AMPLITUDES IC # 1	1X+
2	15.000**	1.000	1X+	1	100.00	90.0	2.0000E+00	-90.0

NORMALIZED MODAL PARTICIPATION FACTOR(S): 100.00 0.0

EIGENVALUE NO. 3 FREQUENCY = 30.000 HZ

EIGENVALUE NO.	FREQUENCY, HERTZ	DAMPING FACTOR, %	MEAS. POS.	MEAS. NO.	NORMALIZED MODE SHAPE	INITIAL PHYSICAL AMPLITUDES IC # 1	1X+

```
     3       30.000**      2.000       1X+       1   100.00   90.0    5.1234E+00   85.5
                        NORMALIZED MODAL PARTICIPATION FACTOR(S):        100.00   -4.5
VAX EXECUTION STATISTICS:
-------------------------

COMPUTER NODENAME AND TYPE:  SDBHR,  VAXstation 3100-M76/GPX

ELAPSED:     0 00:00:06.02  CPU: 0:00:01.12  BUFIO: 53  DIRIO: 140  FAULTS: 809

START DATE/TIME:  24-MAR-1994 15:05
  END DATE/TIME:  24-MAR-1994 15:05
```

10.15 Example Problem EX015

This example demonstrates the following 2 phenomena:

1. the ineffectiveness of output EMAC when N2LAST = N2 and NRH ≤ NCH
2. the ineffectiveness of input EMAC when N3LAST = N3 and NCH ≤ NRH

The ERA analysis in this example satisfies both criteria simultaneously. It uses N2LAST = N2 = 1, N3LAST = N3 = 1, and NRH = NCH = 20. Also, no singular values are truncated causing all EMAC values to be exactly 100%.[230] **EMAC is entirely ineffective as an accuracy indicator under these conditions.** This anomaly never occurs when using the default ERA analysis parameters. By default, N2 = N3 = 1 and N2LAST = N3LAST = 10.

Output file Tape55 (file 55EX15.LIS) contains complete input and output EMAC results. The ITAPES=55 statement in Field 4 of the ERA User Input file activates this output file. Parameter T55CMI=0 causes all EMAC results for all eigenvalues to be printed.[231] Output file Tape50 (file 50EX15.LIS) listed below shows the overall, average EMAC values (Eq. 2-57). All identified eigenvalues in this example have an average EMAC value of 100.00% except for eigenvalue no. 4 which has a value of 99.92%. This slight reduction from 100.00% is due to numerical error caused by the excessively high damping factor of this eigenvalue (69.5%). **Note that there is only 1 true structural mode in this data set (at 25 Hz).**

Here is a listing of file EX015.COM:

```
$! EX015.  SHOW THAT ALL EMACS = 100% WHEN N2LAST = N2, N3LAST = N3,
$!         NCH = NRH, AND NO SINGULAR VALUES ARE TRUNCATED.
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO PROGRAM
$!
```

---

[230] As additional singular values are truncated, EMAC reduces somewhat. However, it is still unusually high whenever N2LAST = N2 and/or N3LAST = N3.

[231] Optional analysis parameter IPREMC = 1 generates additional details of the EMAC calculation on Tape55.

```
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
$!
$ MIMO
ERAEX15.OUT
 &MIMOIN
 T1NAMS='T1EX15_IC1','T1EX15_IC2','T1EX15_IC3','T1EX15_IC4'
 PNOISE = 10
 NIC = 4, INLOC = 2,4,7,8
 NST = 10
 NTIM = 1024
 SF = 100.
 NMODES = 1
 FREQ = 25
 ZETAP  = 1.0
 AMODES = 1.0
 NPTMSR = 43
 &END
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX15.ERA []
$ @ERA EX15
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX15.ERA:

```
$!  EX15.ERA:  EXAMPLE #15
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX15
$!
$ INPUT1:=EX15_IC1
$ INPUT2:=EX15_IC2
$ INPUT3:=EX15_IC3
$ INPUT4:=EX15_IC4
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=20/
```

```
S/MRH=/MRH=20/
S/MIC=/MIC=4/
S/MST=/MST=10/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                       OF AVAILABLE PARAMETERS]
$!
 SF=100
 IORDTU=20,ITAPES=55,T55CMI=0
 N2LAST=1,N3LAST=1,NOFATL(44)=1,NOFATL(45)=1
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!             [ALWAYS USE EXACTLY 5 LINES]
$!
SHOW THAT ALL EMACS=100% WHEN N2LAST=N2,N3LAST=N3,NCH=NRH,
AND NO SINGULAR VALUES ARE TRUNCATED.
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX15:  EXAMPLE #15
```

File 50EX15.LIS

```
* * * ERA -- VERSION 931216 * * *

SHOW THAT ALL EMACS=100% WHEN N2LAST=N2,N3LAST=N3,NCH=NRH,
AND NO SINGULAR VALUES ARE TRUNCATED.
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX15:  EXAMPLE #15


TAPE1 FILE NAMES:
-----------------
   1. []T1EX15_IC1.DAT
   2. []T1EX15_IC2.DAT
   3. []T1EX15_IC3.DAT
   4. []T1EX15_IC4.DAT


-------------------------------------------------------------------------------------------------------------------------
*  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * *

* * * FATAL ERROR NO. 44 IN ERA * * *

DO NOT SET N2LAST EQUAL TO N1.
(IF NRH <= NCH AND NO SINGULAR VALUES ARE TRUNCATED, ALL OUTPUT EMACS WILL BE 100%.)


*  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * *
-------------------------------------------------------------------------------------------------------------------------


* NOFATL( 44) = 1.  FATAL ERROR IS IGNORED *


-------------------------------------------------------------------------------------------------------------------------
*  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * *

* * * FATAL ERROR NO. 45 IN ERA * * *

DO NOT SET N3LAST EQUAL TO N1.
(IF NCH <= NRH AND NO SINGULAR VALUES ARE TRUNCATED, ALL INPUT EMACS WILL BE 100%.)
```

```
*  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * * *  FATAL ERROR  * *
-------------------------------------------------------------------------------------------------------------------------

* NOFATL( 45) = 1.  FATAL ERROR IS IGNORED *

ANALYSIS PARAMETERS:                                                                                          DEFAULT
-------------------                                                                                           VALUE
                (MAX)                                                                                         -------
 NCH .......  20 (   20)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                        MCH
 NRH .......  20 (   20)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                       MRH
 NIC .......   4 (    4)  - NO. OF INITIAL CONDITIONS (INPUTS)                                                   MIC
 NST .......  10 (   10)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                         MST
*NTIM ......   7 ( 1024)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)        -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                        -
*WINDOW ....     0.060    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                             -
 FMIN ......     0.000    - FMIN OF DATA (FOR "ZOOMED" DATA)                                                   0.0

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                               -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                               -
 IORFIR ....  50          - ORDER OF BANDPASS FIR FILTER                                                        50

 NSFRST ....   1          - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                       1
 NSFLAG() ..               - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]  ALL 1
          1111111111
*NSTBOT ....  10          - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                NST

 NGENTH ....   0          - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)   0
*NSTDTA ....  10          - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                         -

 N1 ........   1          - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                      1
 N2 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                          1
 N3 ........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                          1
 N2LAST ....   1          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                   10
 N3LAST ....   1          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                   10

 NSKIP .....   0          - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION               0
 ISTRIP ....   1          - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.               1
 ICAS85 ....   1          - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                        1
 DATABW ....  -999.000     - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1   -

 MODELC ....   0          - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79   0
 MODELD ....   0          - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79   0
 NOAD79 ....   0          - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)      0

*RNKTL0 ....  1.69E-06    - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)                SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....  20           - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION ("IORDER TO USE")                  -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  0.00E+00    - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                          RNKTL0
 2. MXFLAG .  0           - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                               0
 3. POFVAR . 101.0000     - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                      99.999
 4. MXORDR .  20          - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                  0.75 * MIN(NRH,NCH)

 NUMRNK ....   0          -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BYPASSING CRITERIA 1-4 ABOVE   0

 MIDOPT ....   0          - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]          0

 ITAPE(50) .   1          - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                       1
 ITAPE(51) .   0          - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                           0
 ITAPE(55) .   1          - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                               0
 ITAPE(79) .   0          - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                     0
  MXALL ....   0          -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                       0
  MXHANK ...   0          -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                    0
  MXPDQT ...   0          -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                        0
  MXMTM ....   0          -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT      0
  MXMOMC ...   0          -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                     0
  MXDATA ...   0          -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                      0
   MXDNTM ..-999          -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79  MTIM
   MXDNSF ..   1          -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                    1
   MXDNSL ..  10          -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                  NST
   MXDNIF ..   1          -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                    1
   MXDNIL ..   4          -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                  NIC
 ITAPE(80) .   0          - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT   0
  IRUNAV ...   0          - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80     0
 ITAPE(85) .   1          - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85   1
 ITAPE(88) .   0          - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                   0
 ITYDTA ....   3          - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                 3
 MSSCAL ....   2          - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES   2
 IREFTU ....   0          - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)   0
 T55CMI ....     0.0      - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                             1.0
 T88CMI ....     1.0      - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                             1.0
```

```
 MSTO50 ....    0          - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                    0
 MSPP50 ....    1          - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)              1

 LOOPOP ....    0          - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS                 0
  PAR(1) ... -999.00        -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                    -
  PAR(2) ... -999.00        -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                    -
  PAR(3) ... -999.00        -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                    -
  PAR(4) ... -999.00        -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                    -
  PAR(5) ... -999.00        -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                    -
*NCASES ....    1          - NO. OF CONSECUTIVE CASES TO RUN                                                            1

 IPREMC ....    0          - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                   0
 IPRHRS ....    0          - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH  0
 IPRPDQ ....    0          - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                            0
 IPRABC ....    0          - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                        0
 IPREVS ....    0          - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                            0
 IPRREV ....    0          - IF IPRREV=1, PRINT TIME CONSTANTS & INITIAL AMPS OF REAL EIGENVALUES ON TAPE50              0
 IPRDTA ....    0          - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                       0
 IPRPAR ....    0          - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                       0
 MSRTOT ....    0          - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                            0

 IOMAC .....    0          - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1            0
 ---------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ---------------------------------------------------------------


EX15:  EXAMPLE #15

CASE NO.   1:
------------

D(1) =   6.17352E+00

SINGULAR VALUES, D():                                                                                  CUMULATIVE
                                                                                                       % OF
                                                                                  D(N)/D(1)  D(N)/D(N+1) VARIANCE   N
  1 ********************************************************************************************** 1.00E+00     1.213  59.20125   1
  2 ********************************************************************************************  8.25E-01    17.122  99.44705   2
  3 ************************************************                                                 4.82E-02     1.119  99.58434   3
  4 ***********************************************                                                4.30E-02     1.099  99.69405   4
  5 ********************************************                                                   3.92E-02     1.301  99.78492   5
  6 ******************************************                                                     3.01E-02     1.033  99.83862   6
  7 *****************************************                                                      2.92E-02     1.325  99.88898   7
  8 ***************************************                                                        2.20E-02     1.191  99.91764   8
  9 *************************************                                                          1.85E-02     1.007  99.93786   9
 10 ************************************                                                           1.83E-02     1.229  99.95779  10
 11 **********************************                                                             1.49E-02     1.063  99.97099  11
 12 *********************************                                                              1.40E-02     1.252  99.98267  12
 13 *******************************                                                                1.12E-02     1.361  99.99012  13
 14 *****************************                                                                  8.24E-03     1.231  99.99413  14
 15 ***************************                                                                    6.70E-03     1.401  99.99679  15
 16 *************************                                                                      4.78E-03     1.195  99.99814  16
 17 ***********************                                                                        4.00E-03     1.247  99.99908  17
 18 *********************                                                                          3.21E-03     1.460  99.99969  18
 19 ******************                                                                             2.20E-03     3.758  99.99998  19
 20 *                                                                                             5.85E-04            100.00000  20<


INPUT (REFERENCE) COORDINATE CODES:
-----------------------------------
  IC NO.     COORDINATE CODE      MEAS. NO.
    1              2X+                2
    2              4X+                4
    3              7X+                7
    4              8X+                8


* NOTE: FMIN =     0.0000, SF =   100.0000, N1 =  1, ISTRIP =  1.

  THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN      0.0000 &     50.0000 HZ


IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):
------------------------------------------------------------------

   E.V.  FREQUENCY,  DAMPING                                  AVG.    EMACS >= 80%                                                    RECIP-
    NO.     HERTZ    FACTOR, % (ZETA2,%)        CMI,%       EMAC,%  INPUT  OUTPUT      MPC-W   MPC-U   PRC     ARATIO     PROCITY  MSR,%
                                                                     (  4) (  10)
-----------------------------------------------------------------------------------------------------------------------------------------
  1   5   25.405**  -0.816  (-0.816)  :   99.55**  100.00  :      4     10  :  99.55   99.55   974  :  1.067  :  99.3    98.0
-----------------------------------------------------------------------------------------------------------------------------------------
  2   3   19.019+    5.553  ( 5.552)  :   87.09+   100.00  :      4     10  :  87.09   78.66   867  :  0.717  :  28.3     6.1
-----------------------------------------------------------------------------------------------------------------------------------------
  3   8   40.709     9.002  ( 9.002)  :   69.64    100.00  :      4     10  :  69.64   20.73   795  :  0.315  :   9.0     5.2
-----------------------------------------------------------------------------------------------------------------------------------------
```

4	2	18.730	69.511	(69.509)	:	62.47	99.92	:	4	10	:	62.52	31.28	784	: 0.003	: 19.6	8.4
5	4	22.911	-0.088	(-0.088)	:	49.67	100.00	:	4	10	:	49.67	31.18	670	: 1.006	: 37.4	10.3
6	7	40.206	-9.542	(-9.542)	:	42.25	100.00	:	4	10	:	42.25	16.06	711	: 3.356	: 25.2	8.7
7	1	8.303	-23.108	(-9.999)	:	41.71	100.00	:	4	10	:	41.71	41.94	610	: 1.858	: 53.4	5.9
8	6	34.776	-16.294	(-9.999)	:	31.68	100.00	:	4	10	:	31.68	17.11	604	: 6.076	: 38.7	11.8

IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%		EMACS >= 80% INPUT (4)	OUTPUT (10)		MPC-W	MPC-U	PRC		ARATIO		RECIP-PROCITY	MSR,%
1	5	25.405**	-0.816	(-0.816)	:	99.55**	100.00	:	4	10	:	99.55	99.55	974	:	1.067	:	99.3	98.0
2	3	19.019+	5.553	(5.552)	:	87.09+	100.00	:	4	10	:	87.09	78.66	867	:	0.717	:	28.3	6.1
3	8	40.709	9.002	(9.002)	:	69.64	100.00	:	4	10	:	69.64	20.73	795	:	0.315	:	9.0	5.2
4	2	18.730	69.511	(69.509)	:	62.47	99.92	:	4	10	:	62.52	31.28	784	:	0.003	:	19.6	8.4
5	4	22.911	-0.088	(-0.088)	:	49.67	100.00	:	4	10	:	49.67	31.18	670	:	1.006	:	37.4	10.3
6	7	40.206	-9.542	(-9.542)	:	42.25	100.00	:	4	10	:	42.25	16.06	711	:	3.356	:	25.2	8.7
7	1	8.303	-23.108	(-9.999)	:	41.71	100.00	:	4	10	:	41.71	41.94	610	:	1.858	:	53.4	5.9
8	6	34.776	-16.294	(-9.999)	:	31.68	100.00	:	4	10	:	31.68	17.11	604	:	6.076	:	38.7	11.8

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, %	(ZETA2,%)		CMI,%	AVG. EMAC,%		EMACS >= 80% INPUT (4)	OUTPUT (10)		MPC-W	MPC-U	PRC		ARATIO		RECIP-PROCITY	MSR,%
1	1	8.303	-23.108	(-9.999)	:	41.71	100.00	:	4	10	:	41.71	41.94	610	:	1.858	:	53.4	5.9
2	2	18.730	69.511	(69.509)	:	62.47	99.92	:	4	10	:	62.52	31.28	784	:	0.003	:	19.6	8.4
3	3	19.019+	5.553	(5.552)	:	87.09+	100.00	:	4	10	:	87.09	78.66	867	:	0.717	:	28.3	6.1
4	4	22.911	-0.088	(-0.088)	:	49.67	100.00	:	4	10	:	49.67	31.18	670	:	1.006	:	37.4	10.3
5	5	25.405**	-0.816	(-0.816)	:	99.55**	100.00	:	4	10	:	99.55	99.55	974	:	1.067	:	99.3	98.0
6	6	34.776	-16.294	(-9.999)	:	31.68	100.00	:	4	10	:	31.68	17.11	604	:	6.076	:	38.7	11.8
7	7	40.206	-9.542	(-9.542)	:	42.25	100.00	:	4	10	:	42.25	16.06	711	:	3.356	:	25.2	8.7
8	8	40.709	9.002	(9.002)	:	69.64	100.00	:	4	10	:	69.64	20.73	795	:	0.315	:	9.0	5.2

VAX EXECUTION STATISTICS:

COMPUTER NODENAME AND TYPE: SDBRP, VAXstation 3100/GPX

ELAPSED: 0 00:00:10.36 CPU: 0:00:06.09 BUFIO: 83 DIRIO: 113 FAULTS: 967

START DATE/TIME: 21-APR-1994 08:40
END DATE/TIME: 21-APR-1994 08:40

10.16 Example Problem EX016

This examples demonstrates that ERA may identify a very-low-frequency mode as a real eigenvalue (0.0 Hz). The data set includes 2 modes at the following frequencies: 0.01 Hz and 10 Hz. The Tape50 output file (file 50EX16.LIS) listed below shows perfect

identification of the 10 Hz mode, and identification of the 0.01 Hz mode as a real eigenvalue with a large time constant of 157 seconds.[232] Bold type highlights the identified modal parameters.

Here is a listing of file EX016.COM:

```
$! EX016. ILLUSTRATE I.D. OF A VERY-LOW-FREQ. MODE AS A REAL EIGENVALUE.
$!
$! CONSTRUCT TAPE1 FILE USING SISO PROGRAM
$!
$ SISO
T1EX16.DAT   TAPE1 FILE TO CONSTRUCT
1024     NTIM (NO. OF TIME POINTS TO GENERATE)
100      SAMPLING FREQUENCY
0.01     FREQUENCY (HZ) OF MODE 1  (0.0 FOR REAL EIGENVALUE)
1        DAMPING FACTOR (%) OF MODE 1
1        INITIAL AMPLITUDE OF MODE 1
0        INITIAL PHASE (DEGREES) OF MODE 1
Y        MODE MODES ?  Y OR N
10       FREQUENCY (HZ) OF MODE 1  (0.0 FOR REAL EIGENVALUE)
1        DAMPING FACTOR (%) OF MODE 1
1        INITIAL AMPLITUDE OF MODE 1
90       INITIAL PHASE (DEGREES) OF MODE 1
N        MODE MODES ?  Y OR N
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX16.ERA []
$ @ERA EX16
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX16.ERA:

```
$!  EX16.ERA:  EXAMPLE #16
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX16
$!
$ INPUT1:=EX16
```

[232]The 0.01 Hz mode occurs in the data as an exponentially damped COSINE function (initial phase = 0 degrees in program SISO).

```
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=10/
S/MRH=/MRH=10/
S/MIC=/MIC=1/
S/MST=/MST=1/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                      OF AVAILABLE PARAMETERS]
$!
 SF=100
 MIDOPT=1,MXFLAG=1,IPRREV=1
 MSTO50=1,MSPP50=0
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
$!              [ALWAYS USE EXACTLY 5 LINES]
$!
ILLUSTRATE I.D. OF VERY-LOW-FREQ. MODE AS A REAL EIGENVALUE
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX16:  EXAMPLE #16
```

File 50EX16.LIS

```
* * * ERA -- VERSION 931216 * * *

ILLUSTRATE I.D. OF VERY-LOW-FREQ. MODE AS A REAL EIGENVALUE
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX16:  EXAMPLE #16

TAPE1 FILE NAMES:
----------------
   1. []T1EX16.DAT

ANALYSIS PARAMETERS:                                                                                  DEFAULT
-------------------                                                                                    VALUE
                  (MAX)                                                                                -------
 NCH .......  10 (   10)  - NO. OF COLS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                  MCH
 NRH .......  10 (   10)  - NO. OF ROWS IN ERA DATA MATRICES (GENERALIZED HANKEL MATRICES)                  MRH
 NIC .......   1 (    1)  - NO. OF INITIAL CONDITIONS (INPUTS)                                             MIC
 NST .......   1 (    1)  - NO. OF RESPONSE STATIONS (OUTPUTS)    [ = NGENTH + NSTDTA]                      MST
*NTIM ......  38 ( 1024)  - NO. OF TIME SAMPLES USED FROM FREE-RESPONSE FUNCTIONS, INCLUDING NSKIP (MAX.)     -

 SF ........   100.000    - DATA SAMPLING FREQUENCY IN SAMPLES PER SECOND                                     -
*WINDOW ....     0.370    - TOTAL DATA TIME-WINDOW IN SECONDS ( = (NTIM-1-NSKIP)/SF)                         -
 FMIN ......     0.000    - FMIN OF DATA (FOR "ZOOMED" DATA)                                              0.0

 FR1FIR ....  -999.000    - LOWER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                            -
 FR2FIR ....  -999.000    - UPPER FREQUENCY OF BANDPASS FIR FILTER  (-999. = NONE)                            -
 IORFIR ....  50          - ORDER OF BANDPASS FIR FILTER                                                     50

 NSFRST ....   1          - FIRST DATA RECORD NO. TO USE FROM TAPE1 (& COORD.-CODE) FILE(S)                   1
 NSFLAG() ..              - OUTPUTS TO INCLUDE IN DATA MATRICES BELOW ROW NST [CAN BE SELECTED USING KEYDTA=...]  ALL 1
```

```
                1
*NSTBOT ....    1          - NO. OF OUTPUTS ACTIVATED IN NSFLAG()                                                    NST

 NGENTH ....    0          - NO. OF GENERALIZED TIME HISTORIES TO USE (ASSUMED TO BE DATA RECORDS NST-NGENTH+1 THRU NST)   0
*NSTDTA ....    1          - NO. OF DATA RESPONSE STATIONS (DATA OUTPUTS)                                              -

 N1 .........   1          - NO. OF TIME SAMPLES BETWEEN THE 2 DATA MATRICES                                           1
 N2 .........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK ROWS IN THE DATA MATRICES                               1
 N3 .........   1          - NO. OF TIME SAMPLES BETWEEN BLOCK COLS IN THE DATA MATRICES                               1
 N2LAST .....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK ROW (FOR EMAC CALCULATION)                        10
 N3LAST .....  10          - NO. OF TIME SAMPLES TO SHIFT LAST BLOCK COL (FOR EMAC CALCULATION)                        10

 NSKIP ......   0          - NO. OF TIME SAMPLES TO SKIP AT BEGINNING OF EACH FREE-RESPONSE FUNCTION                   0
 ISTRIP .....   1          - ASSUMED Z-PLANE ANGULAR STRIP FOR EIGENVALUES: 1=0-PI; 2=PI-2*PI; ETC.                   1
 ICAS85 .....   1          - CASE NO. TO USE AS THE LABEL FOR FIRST CASE WRITTEN TO TAPE85                            1
 DATABW .....-999.000      - DATA BANDWIDTH (ERA WILL MAKE N1 AS LARGE AS POSSIBLE IF DATABW.NE.-999.)  N2 & N3 SET = N1  -

 MODELC .....   0          - IF =1,2, COMPUTE & WRITE CONTINUOUS [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79   0
 MODELD .....   0          - IF =1,2, COMPUTE & WRITE  DISCRETE  [A,B,C,D] TO TAPE79. IF = 1, STOP AFTER WRITING TAPE79   0
 NOAD79 .....   0          - IF NOAD79=1 (& MODELD=1,2) DO NOT WRITE [AD,BD,CD,DD] TO TAPE79 (MODAL [A,B,C,D] ONLY)      0

*RNKTL0 .... 8.43E-07      - DEFAULT RANK TOLERANCE (BASED ON MACHINE PRECISION--EPS)          SQRT(NRH*NRH+NCH*NCH)*EPS

 IORDTU ....-999           - NO. OF SINGULAR VALUES TO RETAIN--FORCED SELECTION (*IORDER TO USE*)                      -

IF IORDTU = -999 [DEFAULT], SINGULAR VALUE TRUNCATION WILL OCCUR AT THE SMALLEST ORDER AMONG THE FOLLOWING 4 CRITERIA:
-------------------------------------------------------------------------------------------------------------------
 1. RNKTOL .  8.43E-07     - RANK TOLERANCE.  TRUNCATION AT SELECTED VALUE OF D(N)/D(1)                          RNKTL0
 2. MXFLAG .    1          - IF MXFLAG=1, TRUNCATION AT LARGEST VALUE OF D(N)/D(N+1)                                 0
 3. POFVAR .  99.9990      - TRUNCATION AT SELECTED PERCENTAGE OF CUMULATIVE DATA VARIANCE                        99.999
 4. MXORDR .    7          - TRUNCATION AT SELECTED MAX. NO. OF SINGULAR VALUES                    0.75 * MIN(NRH,NCH)

 NUMRNK ....    0          -  * IF NUMRNK=1, TRUNCATE S.V.'S AT NUMERICAL RANK (RNKTL0), BYPASSING CRITERIA 1-4 ABOVE  0

 MIDOPT ....    1          - OPTION FOR ENTERING MEASID() INFO. [COORDINATE CODES ON TC_____ IF MIDOPT=0]              0

 ITAPE(50) .    1          - IF ITAPE(50)=1, WRITE SUMMARY RESULTS TO TAPE50                                          1
 ITAPE(51) .    0          - IF ITAPE(51)=1, WRITE MODE SHAPES (PRINTER PLOTS) TO TAPE51                              0
 ITAPE(55) .    0          - IF ITAPE(55)=1, WRITE INDIVIDUAL EMAC RESULTS TO TAPE55                                  0
 ITAPE(79) .    0          - IF ITAPE(79)=1, WRITE MODAL [A,B,C,D] TO TAPE79 IN MATRIXX FORMAT                        0
  MXALL ....    0          -  * IF MXALL=1, ACTIVATE ALL 5 OF THE FOLLOWING MATRIXX OPTIONS:                          0
  MXHANK ...    0          -  IF MXHANK=1, ALSO WRITE DATA MATRICES TO TAPE79 IN MATRIXX FORMAT                       0
  MXPDQT ...    0          -  IF MXPDQT=1, ALSO WRITE [P,D,QT] TO TAPE79 IN MATRIXX FORMAT                           0
  MXMTM ....    0          -  IF MXMTM =1, ALSO WRITE MODAL TRANSFORMATION MATRIX TO TAPE79 IN MATRIXX FORMAT        0
  MXMOMC ...    0          -  IF MXMOMC=1, ALSO WRITE MOM AND MCM TO TAPE79 IN MATRIXX FORMAT                        0
  MXDATA ...    0          -  IF MXDATA=1, ALSO WRITE TAPE1 DATA TO TAPE79 IN MATRIXX FORMAT                         0
   MXDNTM ..-999            -   IF MXDATA=1, MXDNTM = NO. OF DATA SAMPLES OF EACH TAPE1 RECORD TO WRITE TO TAPE79  MTIM
   MXDNSF ..   1            -   IF MXDATA=1, MXDNSF = FIRST OUTPUT NO. TO WRITE                                       1
   MXDNSL ..   1            -   IF MXDATA=1, MXDNSL =  LAST OUTPUT NO. TO WRITE                                     NST
   MXDNIF ..   1            -   IF MXDATA=1, MXDNIF = FIRST  INPUT NO. TO WRITE                                       1
   MXDNIL ..   1            -   IF MXDATA=1, MXDNIL =  LAST  INPUT NO. TO WRITE                                     NIC
 ITAPE(80) .    0          - IF ITAPE(80)=1, WRITE INPUT MODAL AMPS. AND INSTANTANEOUS FREQ.,DAMPING TO TAPE80 IN .UNV FORMAT  0
  IRUNAV ...    0          - IF IRUNAV=1, RUNNING AVG. OF INSTANTANEOUS FREQ. & DAMPING ALSO WRITTEN TO TAPE80        0
 ITAPE(85) .    1          - IF ITAPE(85)=1, WRITE 1-LINE-PER-EIGENVALUE SUMMARY OF IDENTIFICATION RESULTS TO TAPE85   1
 ITAPE(88) .    0          - IF ITAPE(88)=1, WRITE MODE SHAPES TO TAPE88.UNV IN UNIVERSAL FORMAT                      0
 ITYDTA ....    3          - TYPE OF FRF DATA: 1=D/F, 2=V/F, 3=A/F  (USED TO SCALE TAPE88 RESULTS)                    3
 MSSCAL ....    2          - MODE SHAPE SCALING FOR TAPE88: 0=MPLUS,1=NORMALIZED,-1=NORMALIZED REAL MODE,2=RESIDUES   2
 IREFTU ....    0          - REF. (I.C.) NO. TO USE FOR SCALING RESIDUES TO TAPE88 (USE MAX. RESIDUE AMONG IC'S IF = 0)  0
 T55CMI ....      1.0      - T55CMI IS MINIMUM CMI TO SAVE ON TAPE55                                                 1.0
 T88CMI ....      1.0      - T88CMI IS MINIMUM CMI TO SAVE ON TAPE88                                                 1.0

 MSTO50 ....    1          - IF MSTO50=1, WRITE MODE SHAPES TO TAPE50 (TAPE51 FORMAT)                                 0
 MSPP50 ....    0          - IF MSPP50=0, DO NOT INCLUDE MODE SHAPE PRINTER PLOTS ON TAPE50 (WHEN MSTO50=1)           1

 LOOPOP ....    0          - LOOPING OPTION.  -1 OR 1-9 (SEE ERA$HELP:LOOPOP.LIS).  0 = SINGLE ANALYSIS              0
  PAR(1) ... -999.00        -  OPTIONAL PARAMETER #1 WHEN LOOPOP.NE.0                                                 -
  PAR(2) ... -999.00        -  OPTIONAL PARAMETER #2 WHEN LOOPOP.NE.0                                                 -
  PAR(3) ... -999.00        -  OPTIONAL PARAMETER #3 WHEN LOOPOP.NE.0                                                 -
  PAR(4) ... -999.00        -  OPTIONAL PARAMETER #4 WHEN LOOPOP.NE.0                                                 -
  PAR(5) ... -999.00        -  OPTIONAL PARAMETER #5 WHEN LOOPOP.NE.0                                                 -
*NCASES ....    1          - NO. OF CONSECUTIVE CASES TO RUN                                                           1

 IPREMC ....    0          - IF IPREMC=1, PRINT DETAILS OF EMAC CALCULATION ON TAPE55                                  0
 IPRHRS ....    0          - IF IPRHRS=1, PRINT STRUCTURE OF HRS0 & HRS1 (DATA MATRICES) ON TAPE50; =2, PRINT DATA; =3, BOTH  0
 IPRPDQ ....    0          - IF IPRPDQ=1, P,D,Q MATRICES (SVD OF HRS0) ARE PRINTED ON TAPE50                          0
 IPRABC ....    0          - IF IPRABC=1, A,B,C,D MATRICES ARE PRINTED ON TAPE50                                      0
 IPREVS ....    0          - IF IPREVS=1, EIGENVALUES (Z- AND S-PLANE) ARE PRINTED ON TAPE50                          0
 IPRREV ....    1          - IF IPRREV=1, PRINT TIME CONSTANTS & INITIAL AMPS OF REAL EIGENVALUES ON TAPE50           0
 IPRDTA ....    0          - IF IPRDTA=1, FREE-RESPONSE DATA ARE ECHOED TO TAPE50                                     0
 IPRPAR ....    0          - IF IPRPAR=1, NAMELISTS /ALLP1/ & /ALLP2/ PRINTED ON TAPE50 EACH CASE                     0
 MSRTOT ....    0          - IF MSRTOT=1, PRINT TOTAL MSR (SQRT OF SUM OF SQUARES) ON TAPE50                          0

 IOMAC .....    0          - PRINT INPUT & OUTPUT MODAL AMPLITUDE COHERENCES (OBSOLETE) ON TAPE85 IF IOMAC=1          0
 ---------------------------------------------------------------
*CALCULATED WITHIN ERA SUBROUTINE BASED ON OTHER ANALYSIS PARAMETERS     <-- (FOOTNOTE)
 ---------------------------------------------------------------


EX16:  EXAMPLE #16

CASE NO.   1:
```

D(1) = 1.00397E+01

SINGULAR VALUES, D():

		D(N)/D(1)	D(N)/D(N+1)	CUMULATIVE % OF VARIANCE	N
1	**********	1.00E+00	2.071	70.04822	1
2	**********	4.83E-01	1.095	86.38122	2
3	**********	4.41E-01	90507.695*	100.00000	3
4	++++++++++	4.87E-06		100.00000	4
5	X	0.00E+00		100.00000	5
6	+	0.00E+00		100.00000	6
7	+	0.00E+00		100.00000	7
8	+	0.00E+00		100.00000	8
9	+	0.00E+00		100.00000	9
10	+	0.00E+00		100.00000	10

NUMERICAL RANK = 4

* SINGULAR VALUE TRUNCATION OCCURRED AT ORDER = 3 *

TIME CONSTANTS OF REAL EIGENVALUES:

REAL EV NO. 1, TIME CONSTANT = 9.587E+02 SECS

INITIAL AMPLITUDES OF REAL EIGENVALUES:

REAL EV NO. 1, OUTPUT NO. 1, INPUT NO. 1, AMPLITUDE = 1.000E+00

INPUT (REFERENCE) COORDINATE CODES:

IC NO.	COORDINATE CODE	MEAS. NO.
1	1X+	1

* NOTE: FMIN = 0.0000, SF = 100.0000, N1 = 1, ISTRIP = 1.

THE FOLLOWING RESULTS WERE CALCULATED ASSUMING THAT ALL MODES LIE BETWEEN 0.0000 & 50.0000 HZ

IDENTIFICATION RESULTS, SORTED BY CONSISTENT-MODE INDICATOR (CMI):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, % (ZETA2,%)		CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	OUTPUT (1)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	10.000**	1.000	(1.000)	99.99**	99.99	1	1	-999.00	-999.00	-999	0.798	-999.0	55.1

IDENTIFICATION RESULTS, SORTED BY MODAL PHASE COLLINEARITY (MPC-W):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, % (ZETA2,%)		CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	OUTPUT (1)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	10.000**	1.000	(1.000)	99.99**	99.99	1	1	-999.00	-999.00	-999	0.798	-999.0	55.1

IDENTIFICATION RESULTS, SORTED BY FREQUENCY (FD):

E.V. NO.		FREQUENCY, HERTZ	DAMPING FACTOR, % (ZETA2,%)		CMI,%	AVG. EMAC,%	EMACS >= 80% INPUT (1)	OUTPUT (1)	MPC-W	MPC-U	PRC	ARATIO	RECIP-PROCITY	MSR,%
1	1	10.000**	1.000	(1.000)	99.99**	99.99	1	1	-999.00	-999.00	-999	0.798	-999.0	55.1

```
                                        ---------------------------------------------
                                        EIGENVALUE NO.  1       FREQUENCY =   10.000 HZ
                                        ---------------------------------------------

EIGENVALUE  FREQUENCY,   DAMPING    MEAS.   MEAS.   NORMALIZED      ---------- INITIAL PHYSICAL AMPLITUDES ----------
   NO.        HERTZ     FACTOR, %   POS.    NO.    MODE SHAPE        IC # 1     1X+

     1       10.000**     1.000      1X+      1   100.00   90.0    9.9998E-01   90.0

                      NORMALIZED MODAL PARTICIPATION FACTOR(S):       100.00     0.0

VAX EXECUTION STATISTICS:
-------------------------

COMPUTER NODENAME AND TYPE:  SDBRP,  VAXstation 3100/GPX

ELAPSED:    0 00:00:05.84  CPU: 0:00:01.84  BUFIO: 53  DIRIO: 113  FAULTS: 795

START DATE/TIME:  21-APR-1994 10:17
  END DATE/TIME:  21-APR-1994 10:18
```

10.17 Example Problem EX017

This example compares ζ (Eq. 2-34) and ζ_2 (Eq. 2-70) by Monte Carlo analysis of noisy data. Program MIMO constructs 50 sets of single-input/single-output data with 1 structural mode (20 Hz and 1% damping) and a noise level of 1%. Each data set uses a different sequence of random numbers as the noise term. ERA analyzes all 50 data sets in sequence by including the following command in Field 4 of the User Input file:

```
LOOPOP=-1,PAR=1,50,1
```

The relative accuracy of ζ and ζ_2 in general is not yet established. In this example, ζ_2 is approximately twice as accurate (the magnitude of the random error) as ζ. **Fig. 10-6** shows the results. It is generated with GO Input file G15_4_LO-1_EX17.COM.

The ERA analysis required approximately 61 seconds of CPU time on the author's VAXstation 3100 computer.

Here is a listing of file EX017.COM:

```
$! EX017. COMPARE ZETA AND ZETA2 USING MONTE CARLO ANALYSIS OF
$!         NOISY DATA (50 CASES).
$!
$! CONSTRUCT TAPE1 FILE(S) USING MIMO PROGRAM
$!
$! ALL PARAMETERS ENTERED VIA NAMELIST/MIMOIN/
$!
$ MIMO
ERAEX17.OUT
 &MIMOIN
 T1NAMS='T1EX17'
 PNOISE = 1
 NIC = 1, INLOC = 1
 NST = 1
 NTIM = 1024
```

```
 SF = 100.
 NMODES = 1
 FREQ = 20.0
 ZETAP  = 1.0
 AMODES = 1.0
 NPTMSR = 43
 NCASES = 50
 &END
$!
$! RUN ERA INTERACTIVELY
$!
$ COPY ERA$OEXS:EX17.ERA []
$ @ERA EX17
$!
$ EXIT
```

Here is a listing of the ERA User Input file for this problem, EX17.ERA:

```
$!  EX17.ERA:  EXAMPLE #17
$!
$!   ---------- FIELD 1: INPUT & OUTPUT DIRECTORIES ----------
$! [MODIFY DIRECTORY NAMES ONLY; '[]' SELECTS DEFAULT DIRECTORY]
$!
$ DEFINE ERA_INPUT$  []
$ DEFINE ERA_OUTPUT$ []
$!
$! ---------- FIELD 2: JOB & TAPE1 (& COORD-CODE) FILENAME SUFFICES ----------
$!       [MODIFY INFORMATION TO THE RIGHT OF THE EQUAL SIGNS ONLY]
$!
$ JOBNAME:=EX17
$!
$ INPUT1:=EX17
$!
$! ---------- FIELD 3: DIMENSIONS (= DEFAULT NCH,NRH,NIC,NST) ----------
$! [MODIFY NUMBERS ONLY: MCH  = MAX. NO. OF COLS IN GEN. HANKEL MATRICES
$!                       MRH  = MAX. NO. OF ROWS IN GEN. HANKEL MATRICES
$!                       MIC  = MAX. NO. OF INITIAL CONDITIONS (INPUTS)
$!                       MST  = MAX. NO. OF RESPONSE STATIONS (OUTPUTS)
$!                       MTIM = NO. OF TIME PTS. IN EACH TAPE1 RECORD]
S/MCH=/MCH=10/
S/MRH=/MRH=10/
S/MIC=/MIC=1/
S/MST=/MST=1/
S/MTIM=/MTIM=1024/
$!
$!  ---------- FIELD 4: ANALYSIS PARAMETERS ('SF' REQUIRED) ----------
$!  [NAMELIST FORMAT: COLUMN 1 BLANK; SEE TAPE50 FOR COMPLETE LIST
$!                    OF AVAILABLE PARAMETERS]
$!
 SF=100,MIDOPT=1
 LOOPOP=-1,PAR=1,50,1
$!
$! ---------- FIELD 5: 5-LINE JOB DESCRIPTION ----------
```

```
$!              [ALWAYS USE EXACTLY 5 LINES]
$!
COMPARE ZETA & ZETA2 USING MONTE CARLO ANALYSIS (50 CASES)
LINE 2 FOR ADDITIONAL COMMENTS
LINE 3 FOR ADDITIONAL COMMENTS
LINE 4 FOR ADDITIONAL COMMENTS
EX17:  EXAMPLE #17
```

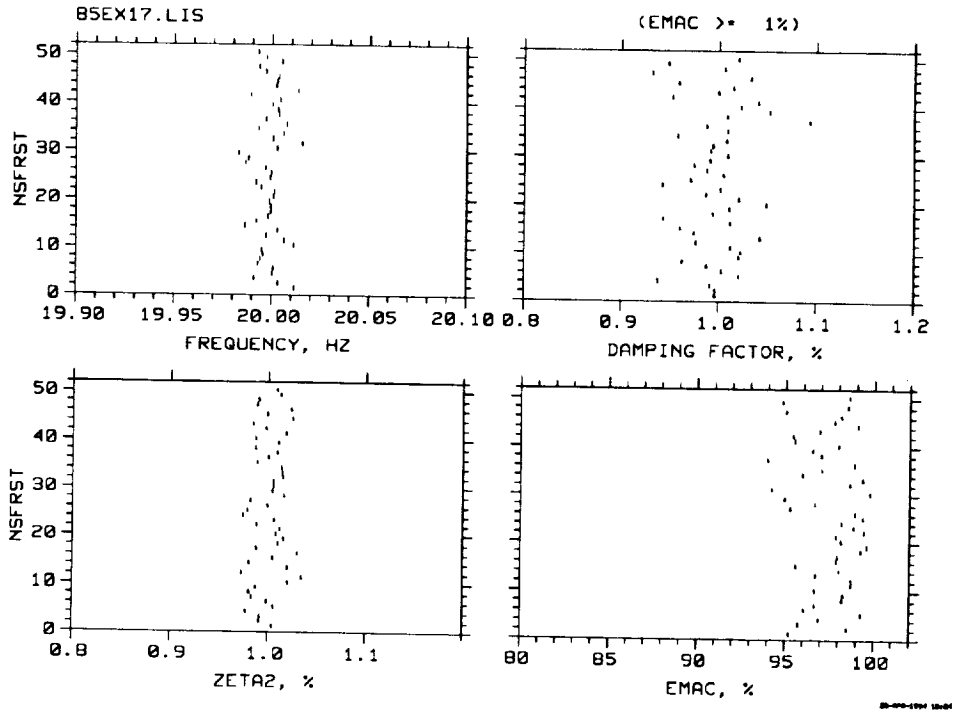


Fig. 10-6. Comparison of ZETA and ZETA2 [G15_4_LO-1_EX17.COM]

11.0 COMMON MISTAKES

1. Analysis parameter IORDTU is used to select a particular number of retained singular values (i.e., the order of the eigenvalue problem to solve). IORDTU is an acronym for "Order to Use." **IORDTU equals twice the assumed number of modes.** There is no method to select a particular number of assumed modes except using parameter IORDTU which you should set equal to twice the desired number of assumed modes.

2. Do not include "T1" at the beginning of the Tape1 (and Coordinate-Code) file names specified in Field 2 of the User Input file. Only specify the file name suffices (i.e., **leave off the "T1"**). If you specify INPUT1:=TEST, for example, the software will access a Tape1 data file named T1TEST.DAT and a corresponding Coordinate-Code file named TCTEST.DAT.

3. Do not execute input files for the pre- and post-processors using the traditional DCL "@" command rather than "GO". (Actually, using "@" is normally okay for the non-graphics programs (those named ERAPnn) but is not okay for the graphics programs (those named ERAGnn)).

4. When analyzing bandlimited data generated by ERAP20 (or directly from certain commercial FFT analyzers using "zoom transform" methods), do not forget to include the correct FMIN and SF parameters in Field 4 of the User Input file. These values are printed at the end of the listing when ERAP20 is run. FMIN equals the lowest retained frequency, and SF equals twice the data bandwidth (i.e., 2 * (FMAX - FMIN)).

5. You can add as many comments[233] as you like at the beginning of an ERA User Input file (before Field 1). However, never add comments anywhere else in the file or the automatic editing process invoked by ERA.COM will seriously malfunction. Also, never use 10 or more consecutive dashes in your comments; that sequence of characters is used to distinguish the various sections of the file for the editor.

6. Users will occasionally misspell one of the analysis parameters specified in Field 4 of the User Input file. If you do, you will receive the following obscure error message if the analysis is run as a batch job (using "ERA"):

Job ERA (queue SYS$BATCH, entry 829) terminated with error status
%FOR-F-INVREFVAR, invalid reference to variable "!AS" in NAMELIST input!/ unit !SL file !AS

[233]Comment lines begin with "$!".

If the analysis is run interactively (using "@ERA"), the error message is much more descriptive. For example, if you misspell parameter LOOPOP as "LOOPOPT", you will receive the following message:

```
%FOR-F-INVREFVAR, invalid reference to variable "LOOPOPT" in NAMELIST input
 unit 77  file SDBRP$DKA0:[ERA.TESTCASES]77_TEMP.TMP;3
 user PC 0000F493
```

7. Job names specified in Field 2 of the User Input file can be no longer than 26 characters in length. If you specify a job name greater than 26 characters in length, you will receive the following error message on your terminal screen when ERA is submitted as a batch job:

```
Job ERA (queue SYS$BATCH, entry 43) completed
%RMS-F-FNM, error in file name
```

If you run ERA interactively (using **@ERA**), no error message is given, but the job terminates almost immediately.

8. Specifying '[]' as a directory name in Field 1 of the User Input file refers to your LOGIN directory if you run ERA as a batch job, but refers to your current default directory if you run ERA interactively or as a spawned subprocess. Using explicit directory names avoids this problem.

9. All ERA-identified frequencies are damped natural frequencies, unless otherwise noted. With typical structural dynamics data having modal damping of a few percent or less, there is negligible difference between damped and undamped natural frequencies. The relationship between damped natural frequencies, f_d, and undamped natural frequencies, f_n, is

$$f_d = f_n\sqrt{1-\zeta^2}$$

where ζ is the modal damping factor (fraction of critical damping).

10. FORTRAN NAMELIST syntax (Field 4 of the ERA User Input file) requires at least 1 blank space at the beginning of every line.

12.0 MISCELLANEOUS TOPICS

12.1 Running Graphics Pre- and Post-Processors as Batch Jobs

The following command procedure demonstrates how graphics pre- and post-processors (programs beginning with "ERAG") can be run as batch jobs to generate PostScript output. The file is named BATCH_GRAPHICS_DEMO.COM and is stored in directory ERA$MISC.

```
$! BATCH_GRAPHICS_DEMO.COM
$!
$! SAMPLE COMMAND FILE FOR RUNNING ERA GRAPHICS PRE- AND POST-PROCESSORS
$! (PROGRAMS BEGINNING WITH "ERAG") IN BATCH MODE WITH POSTSCRIPT OUTPUT.
$!
$! THIS EXAMPLE RUNS GO INPUT FILES G1T_DEMO.COM AND G1F_DEMO.COM
$! STORED IN DIRECTORY ERA$GO
$!
$! R.PAPPA
$!
$! CHOOSE A POSTSCRIPT PRINTER
$! (PSNY IS A DCL SYMBOL WHICH EXECUTES THE FOLLOWING COMMAND:
$!  DEFINE PS_OUTPUT_DEVICE SDBNY::CSA0:)
$!
$ PSNY
$!
$! IN THE FOLLOWING STATEMENT,
$!  DEFINE FOR099 = ERA$UTIL:PS_TALL_FOR099 FOR TALL POSTSCRIPT OUTPUT
$!  DEFINE FOR099 = ERA$UTIL:PS_WIDE_FOR099 FOR WIDE POSTSCRIPT OUTPUT
$!
$ DEFINE FOR099 ERA$UTIL:PS_WIDE_FOR099
$!
$! WARNING:
$!  EXECUTE THE GO INPUT FILES USING '@', NOT 'GO'.
$!
$ SET DEFAULT ERA$GO
$!
$ @G1T_DEMO
$ @G1F_DEMO
```

12.2 Erasing Tektronix Graphics

On certain terminals, it is necessary to clear Tektronix graphics from the computer screen before entering additional DCL commands. This can be accomplished conveniently by entering the command ET, which is an acronym for "Erase Tektronix."

12.3 Bypassing Fatal Errors in ERA

All fatal errors generated by ERA can be bypassed by including the following statement in Field 4 of the User Input file:

```
NOFATL(N) = 1
```

to bypass fatal error number N. NOFATL() is an on/off switch (1=on, 0=off). By default, all elements of NOFATL() are 0.

If you bypass a fatal error, the error message is still printed on Tape50. However, it is immediately followed by the following statement:

```
* NOFATL(N) = 1.  FATAL ERROR IS IGNORED *
```

for error number N.

Note: NOFATL() is a "hidden" analysis parameter. It is **not** included in the list of parameters printed at the beginning of Tape50.

Appendix C lists all fatal and warning errors generated by ERA.

12.4 Hidden Options in Pre- and Post-Processors

Hidden options are software features of some pre- and post-processors which are used only occasionally and/or by particular users. A knowledgeable user can select these additional features while regular users (i.e., users who do not have the appropriate options file in their current default directory) are unaffected.

As an example, a hidden option is available with program ERAG1 to draw a border around the edge of the plotting area. This option is activated in the following way. ERAG1 looks for a file named G1_OPTIONS.DAT in your current default directory before processing the responses from the GO input file. If this file is found, its contents are read using a NAMELIST read command. The variables you include in the G1_OPTIONS.DAT file must be declared in a NAMELIST group named G1_OPTIONS (i.e., they must be placed between a ' $G1_OPTIONS' card and a ' $END' card[234]). For example, a border will be drawn around the edge of the plot generated by ERAG1 if file G1_OPTIONS.DAT contains the following 3 lines of code:

```
$G1_OPTIONS
IBORDR=1
```

[234]You may use an ampersand instead of a dollar sign on the ' $G1_OPTIONS' and ' $END' cards.

```
$END
```

Setting variable IBORDR equal to 1 causes the border to be drawn. Recall that NAMELIST syntax requires a leading blank character at the beginning of each line.

Hidden options for other pre- and post-processors are implemented in a similar manner. Documentation of hidden options is provided in directory ERA$PP_OPTIONS and/or at the beginning of the corresponding source-code file (all source files are stored in directory ERA$SOURCES).

ERAG1 looks for file G1_OPTIONS.DAT in your current default directory. If it exists, the contents of the file are read and echoed on the computer screen. You are then asked if it is okay to continue, as follows:

```
*** WARNING.  HIDDEN OPTIONS READ IN FROM FILE G1_OPTIONS:
$G1_OPTIONS
IBORDR  =           1
$END

O.K. TO CONTINUE ?  1=YES  (1)
```

Entering a "1" or a Carriage Return (selecting the default value) causes ERAG1 to proceed. All other responses cause the program to stop.

12.5 Redirecting the Output of Pre- and Post-Processors to a Disk File

When running pre- and post-processors using GO, the questions and responses often scroll by on the computer screen at a rate too fast to read. To examine this information more closely, you can redirect the terminal display to a disk file. This can be accomplished conveniently by simply appending an additional file name. For example:

```
GO P2_DEMO P2.OUT
```

Everything that would normally appear on your computer screen is now redirected to file P2.OUT instead.

12.6 Modifying Default Axis Numbers on Plots

Axis numbers appearing on plots are selected internally by the DIGLIB software. These selections are sometimes unsatisfactory. As an example, **Fig. 12-1** shows the default x-axis numbers selected by DIGLIB when a frequency interval from 21 to 22 Hz is requested using ERAG7. A total of 11 tic marks are numbered. For report purposes this is considered excessive (labels every 0.2 Hz are preferred).

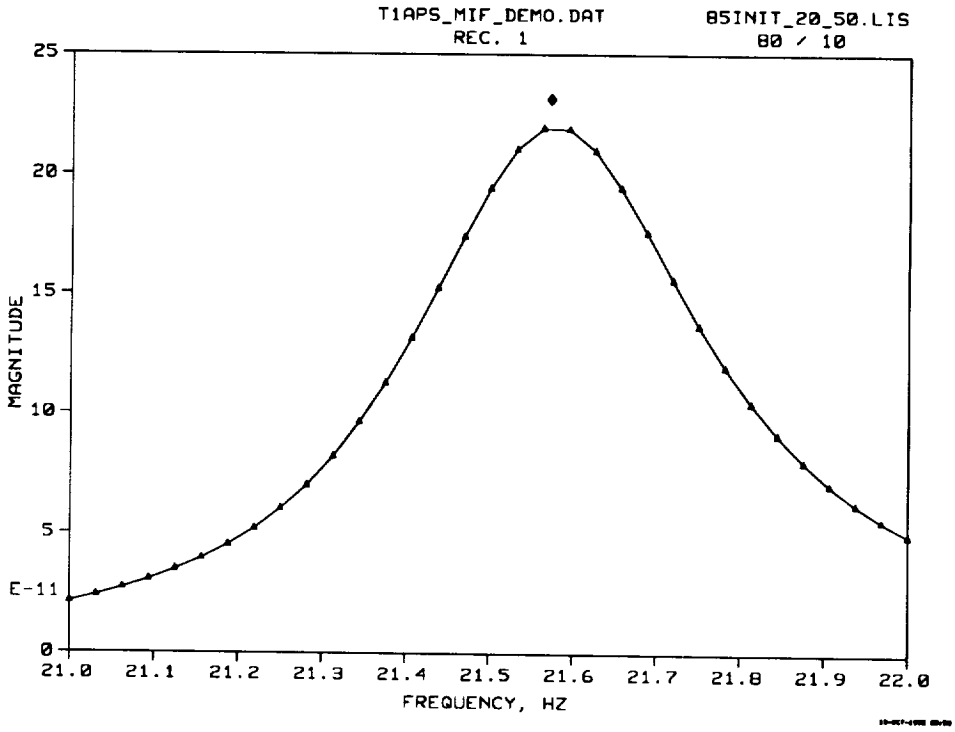


Fig. 12-1. Unsatisfactory Default X-Axis Numbers [G7_21_22_DEMO.COM]

You may select alternative axis numbers by answering "yes" (entering a "1") to the following question asked by every graphics program:

```
MODIFY DEFAULT AXIS NUMBERS ?  1=YES
```

If you respond with "yes," you are asked additional questions. For each axis, the software prints the current values of the start, end, and delta axis numbers, and a power of 10 applied to all 3 numbers. **All 4 of these parameters must be integers.** You are asked if you wish to modify the current values. If so, enter a "1" followed by the desired values. If not, enter a "0." For example, GO input file G7_21_22_MODNUMS_DEMO.COM (listed below) generates the preferred x-axis labels shown in **Fig. 12-2**.

```
$! G7_21_22_MODNUMS_DEMO.COM
$!
$ RUN ERA$EXES:ERAG7
T1APS_MIF_DEMO      TAPE1 FILENAME
1            FIRST RECORD TO PLOT
1            LAST RECORD TO PLOT
1            RECORD INCREMENT BETWEEN PLOTS
1            NO. OF PLOTS TO PLACE HORIZONTALLY ON PAGE
1            NO. OF PLOTS TO PLACE VERTICALLY ON PAGE
1            NO. OF CONSECUTIVE FUNCTIONS TO OVERLAY IN EACH PLOT
```

```
1             LINE STYLE?  1=SOLID, 2=SOLID & 3 DASHED (CYCLICALLY), 3=SOLID LINE...
0             LINEAR(0) OR LOG(1) SPECTRUM MAGNITUDE PLOT?
0,25E-11      MIN., MAX. FOR MAGNITUDE AXIS ?  0,0 = AUTOSCALE
1             HIGHLIGHT EACH PT. ON SPECTRUM WITH A SYMBOL?  1=YES
0             INCLUDE COORDINATE CODES?  1=YES
160           SAMPLING FREQ., HZ
0             DATA FMIN
              NO. OF POINTS TO FOURIER TRANSFORM (DEFAULT = ALL)
0             USE HANNING WINDOW?  1=YES
0             REMOVE DC VALUE?  1=YES
21            FMIN TO PLOT (DEFAULT = DATA FMIN)
22            FMAX TO PLOT (DEFAULT = SF/2 + DATA FMIN)
.1            DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS
0.0           FREQ. FOR FIRST X-AXIS MINOR TIC MARK.  0.0 = ORIGIN OF PLOT
0             PLOT ABS(IMAG. PART) RATHER THAN MODULUS?  1=YES
1             SKIP SPECTRUM PHASE PLOT?  1=YES
0             INCLUDE X-AXIS GRID LINES ON FREQ. PLOT?  1=YES
0             ADD ADDITIONAL DOTTED VERTICAL LINES AT MINOR TICS?  1=YES
0.3           CHARACTER SIZE IN CM
1             FONT TYPE.  1=STICK
0             PRINT OUT SPECTRUM TO FILE G1_SPECTRUM.OUT?  1=YES
85INIT_20_50   TAPE85 FILE
1             CASE NO. TO USE FROM TAPE85
80            MINIMUM CMI FOR DARKENED SYMBOLS
10            MINIMUM CMI FOR   OPEN   SYMBOLS
1.0           SYMBOL SIZE, AS A FRACTION OF CHARACTER SIZE
1             USE DEFAULT OVERALL WINDOW SIZE?  1=YES
1             MODIFY DEFAULT AXIS NUMBERS?  1=YES
1                 MODIFY X-AXIS NUMBERS ?  1=YES
210,220,2,-1      NEW START,END,DELTA,POWER OF 10 [ALL MUST BE INTEGERS !!!]
0                 MODIFY Y-AXIS NUMBERS ?  1=YES
```

The following information is printed on your computer screen when G7_21_22_MODNUMS_DEMO is run (after specifying a graphics device):

```
START,END,DELTA,POWER OF 10 =   210   220     1    -1
MODIFY THESE AXIS LABELS FOR X-AXIS ?  1=YES  (0)
         1
ENTER START,END,DELTA,POWER OF 10 FOR AXIS LABELS [ ENTER INTEGERS ONLY !!! ] ?
       210       220         2        -1

START,END,DELTA,POWER OF 10 =     0    25     5   -11
MODIFY THESE AXIS LABELS FOR Y-AXIS ?  1=YES  (0)
     0
```

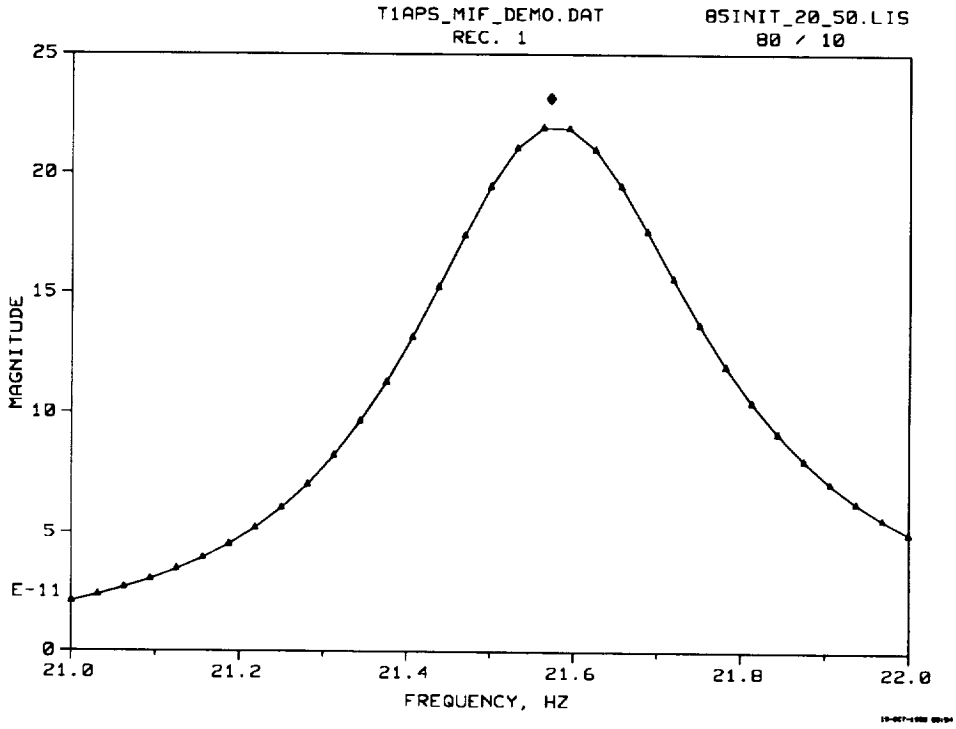


Fig. 12-2. User-Specified X-Axis Numbers [G7_21_22_MODNUMS_DEMO.COM]

12.7 Identification of Real Eigenvalues

ERA is fully capable of identifying both real and complex-conjugate pairs of eigenvalues. In structural dynamic applications, only the complex-conjugate pairs of eigenvalues (underdamped modes) are normally of interest. Therefore, the real-eigenvalue results are not provided on Tape50, 51, 55, 85, or 88. These results are included in the Tape79 output (for MATRIXx or MATLAB) used primarily in control applications. Real eigenvalues are also printed on Tape50 if parameter IPREVS = 1 is specified in Field 4 of the User Input file. IPREVS is an acronym for "Print Eigenvalues." Furthermore, if IPRREV = 1, the time constants and initial amplitudes of the real eigenvalues are also printed on Tape50. IPRREV is an acronym for "Print Real Eigenvalues."

Identification of real eigenvalues is demonstrated in Example Problem EX003 discussed in Chapter 10.

12.8 Modification of Dimensions in a Pre- or Post-Processor and Recompilation

If the dimensions in certain pre- or post-processors are too large relative to system resources available to the user, the following error may occur during execution:

```
  %DCL-W-ACTIMAGE, error activating image ERA$EXES:ERAPxx
-CLI-E-IMGNAME, image file Disk_name:[ERA.EXES]ERAPxx.EXE;1
        -SYSTEM-F-EXQUOTA, exceeded quota
```

If you cannot obtain permission to use additional system resources, the dimensions in the program must be reduced. All source files are stored in directory ERA$SOURCES. After modification, the program is recompiled by typing `@C` followed by the file name. For example, to recompile program ERAP25, enter

```
@C ERAP25
```

while in directory ERA$SOURCES. The following information appears on your computer screen:

```
$!
$ DELETE ERA$EXES:ERAP25.EXE;*
%DELETE-I-FILDEL, SDBRP$DKA0:[ERA.EXES]ERAP25.EXE;1 deleted (57 blocks)
$!
$ FORTRAN/CHECK=(BOUNDS,OVERFLOW) -
         /OBJECT=ERA$OBJS:ERAP25.OBJ -
         /NOLIST -
          ERA$SOURCES:ERAP25.FOR
$ LINK/EXE=ERA$EXES:ERAP25 ERA$OBJS:ERAP25,RSPLIB/LIB
$ DELETE ERA$OBJS:ERAP25.OBJ;*
%DELETE-I-FILDEL, SDBRP$DKA0:[ERA.OBJS]ERAP25.OBJ;1 deleted (63 blocks)
$!
$ SET NOVERIFY
```

If the dimensions are still too large, you will receive the following error message during recompilation:

```
%LINK-E-EXPAGQUO, exceeded page file quota
 -LINK-E-NOIMGFIL, image file not created
```

12.9 Viewing the Execution of ERA.COM

The individual steps in the ERA command procedure, ERA.COM, can be viewed by executing ERA interactively using the `@ERA` command, and appending a "1" (leaving a

space after the file name). For example, to view each step of ERA.COM for job SISO1, move into the ERA$TESTCASES directory and execute ERA as follows:

```
@ERA SISO1 1
```

This capability was developed for debug purposes.

12.10 Increasing the Software Limit of 20 Inputs

The software is currently limited to the use of 20 inputs (Tape1 files) simultaneously. This limit is easily increased (to any value) by modifying variable MAX_INPUTS appearing near the beginning of file ERA$COMS:ERA.COM.

12.11 Saving PostScript Files

If you request PostScript output, the PostScript file is send to a printer having the logical name PS_OUTPUT_DEVICE. This logical name is defined in the ERA setup file, ERA$:SUERA.COM. Comments in the SUERA.COM file describe how to assign the default printer. (Your system manager has probably already done this for you.) To use a printer other than the default device, simply redefine PS_OUTPUT_DEVICE in your personal LOGIN.COM file after the @[ERA]SUERA command is given. Alternatively, you can place the command in a file named SUERA_USER.COM stored in your login directory. After command procedure SUERA.COM defines all variables for ERA, it searches your login directory for a file named SUERA_USER.COM which is then executed if found.

The PostScript file is deleted after it is routed to the printer. If you would like to save this file, enter the command

```
SAVEPS
```

which is an acronym for "Save PostScript files." The following message appears on your computer screen:

```
$ LWP_DELETE_PS :== NO
$ SET NOVERIFY
```

PostScript files are now saved after they are printed.[235] They reside in your login directory with the name POSTSCRIPT.*TIMECODE*, where *TIMECODE* is a unique string of characters corresponding to the date and time of file creation.[236]

---

[235]The file is always printed whether or not it is also saved as a disk file.

[236]**Note:** PostScript graphics output is saved as file POSTSCRIPT.*TIMECODE* in your login directory. PostScript text output (such as generated using command `LW132`), however, is saved as file LASER_TEXTFILE.PS in your current default directory.

To return to the default condition of having PostScript files deleted after they are printed, enter:

```
DELPS
```

to "Delete PostScript files."

At NASA Langley, users can send PostScript output to the laser printer attached to the SDBNY computer (device SDBNY::CSA0:) by typing:

```
PSNY
```

The following message appears on your computer screen showing that PS_OUTPUT_DEVICE is assigned to device SDBNY::CSA0:

```
$ DEFINE PS_OUTPUT_DEVICE  SDBNY::CSA0:
%DCL-I-SUPERSEDE, previous value of PS_OUTPUT_DEVICE has been superseded
$ SHOW LOGICAL PS_OUTPUT_DEVICE
   "PS_OUTPUT_DEVICE" = "SDBNY::CSA0:" (LNM$PROCESS_TABLE)
$ SET NOVERIFY
```

Similarly, the commands **PSRSM** and **PSDC** redirect PostScript output to printers attached to the SDBRSM and SDBDC computers, respectively. Definitions of **PSNY**, **PSRSM**, and **PSDC** appear in the ERA set up file ERA$:SUERA.COM. Your system manager can easily modify this file to define other symbols for your convenience. At NASA Langley, the default PostScript printer for ERA output is SDBNY::CSA0:.

Plotting Data Records From Multiple Tape1 Files

To plot 2 or more data records from separate Tape1 files with program ERAG1, you must first copy them into a single file. Use program ERAP5 and the VMS COPY and APPEND commands for this purpose. The example below illustrates the procedure by performing a reciprocity check of Driving Points 1 and 3 for the demonstration problem. By Maxwell's Reciprocity Theorem, the FRF from excitation point A to response point B equals the FRF from excitation point B to response point A. Good reciprocity of FRFs is necessary for multiple-input modal identification techniques such as ERA. Poor reciprocity occurs for inconsistent and/or nonlinear data.

Construct the necessary Tape1 and Coordinate-Code files for this reciprocity check using file BUILD_SH1_SH3_RECIP_DEMO.COM. Here is a listing of this file:

```
$! BUILD_SH1_SH3_RECIP_DEMO.COM
$!
$ SET VERIFY
```

```
$!
$ COPY ERA$GO:P5_201Z_203Z_DEMO.COM []
$ GO P5_201Z_203Z_DEMO
$!
$ COPY ERA$GO:P5_203Z_201Z_DEMO.COM []
$ GO P5_203Z_201Z_DEMO
$!
$ SET VERIFY
$ COPY   T1_201Z_203Z.DAT T1_SH1_SH3_RECIPROCITY.DAT
$ APPEND T1_203Z_201Z.DAT T1_SH1_SH3_RECIPROCITY.DAT
$!
$ COPY   TC_201Z_203Z.DAT TC_SH1_SH3_RECIPROCITY.DAT
$ APPEND TC_203Z_201Z.DAT TC_SH1_SH3_RECIPROCITY.DAT
$!
$ SET NOVERIFY
```

Copy file BUILD_SH1_SH3_RECIP_DEMO.COM into your working directory and execute as a standard VMS command procedure as follows:

```
COPY ERA$GO:BUILD_SH1_SH3_RECIP_DEMO.COM []

@BUILD_SH1_SH3_RECIP_DEMO
```

The following information appears on your computer screen when BUILD_SH1_SH3_RECIP_DEMO.COM is run:

```
$ COPY ERA$GO:P5_201Z_203Z_DEMO.COM []
$ GO P5_201Z_203Z_DEMO
$ SET NOVERIFY

ERAP5.  EXTRACT VARIOUS PORTIONS OF VARIOUS RECORDS FROM A TAPE1
DATA FILE.

ENTER INPUT TAPE1 FILE NAME,'  [DEFAULT FILE TYPE = .DAT]
T1_MMST_NAS_SH1.DAT

ENTER OUTPUT TAPE1 FILE NAME,'  [DEFAULT FILE TYPE = .DAT]
T1_201Z_203Z.DAT

COORDINATE-CODE FILE AVAILABLE?  1=YES  (1)
          1

INPUT COORDINATE-CODES READ FROM FILE:
TC_MMST_NAS_SH1.DAT

OUTPUT COORDINATE-CODES WRITTEN TO FILE:
TC_201Z_203Z.DAT

EACH RECORD ON TAPE1 CONTAINS   5120 DATA PTS. (NTIM)

NSKIP (NO. OF DATA PTS. TO SKIP AT BEGINNING OF EACH RECORD) ?  (0)
```

```
          0

DATA PARSING FACTOR ?  (1):
 1 = EXTRACT VERY DATA PT.
 2 = EXTRACT EVERY 2ND DATA PT.
 ETC.
          1

NTIM (OUTPUT) ?  (  5120)
       5120

ENTER LIST OF RECORD NOS. AS A RANGE (1) OR AS A LIST OF VALUES (2) ?  (1)
          1

FIRST RECORD NO. TO EXTRACT ?  (1)
        104

LAST RECORD NO. TO EXTRACT ?  (1000)
        104
EXTRACTED RECORD  104:      104     201       3     203       3

DATA RECORDS WRITTEN TO FILE:
 T1_201Z_203Z.DAT

   NST =          1
 NSKIP =          0
  NTIM =       5120


$ COPY ERA$GO:P5_203Z_201Z_DEMO.COM []
$ GO P5_203Z_201Z_DEMO
$ SET NOVERIFY

ERAP5.  EXTRACT VARIOUS PORTIONS OF VARIOUS RECORDS FROM A TAPE1
DATA FILE.

ENTER INPUT TAPE1 FILE NAME,'  [DEFAULT FILE TYPE = .DAT]
T1_MMST_NAS_SH3.DAT

ENTER OUTPUT TAPE1 FILE NAME,'  [DEFAULT FILE TYPE = .DAT]
T1_203Z_201Z.DAT

COORDINATE-CODE FILE AVAILABLE?  1=YES  (1)
          1

INPUT COORDINATE-CODES READ FROM FILE:
TC_MMST_NAS_SH3.DAT

OUTPUT COORDINATE-CODES WRITTEN TO FILE:
TC_203Z_201Z.DAT

EACH RECORD ON TAPE1 CONTAINS   5120 DATA PTS. (NTIM)

NSKIP (NO. OF DATA PTS. TO SKIP AT BEGINNING OF EACH RECORD) ?  (0)
```

```
          0

DATA PARSING FACTOR ?  (1):
 1 = EXTRACT VERY DATA PT.
 2 = EXTRACT EVERY 2ND DATA PT.
 ETC.
          1

NTIM (OUTPUT) ?  (  5120)
       5120

ENTER LIST OF RECORD NOS. AS A RANGE (1) OR AS A LIST OF VALUES (2) ?  (1)
          1

FIRST RECORD NO. TO EXTRACT ?  (1)
        103

LAST RECORD NO. TO EXTRACT ?  (1000)
        103
EXTRACTED RECORD  103:      103     203       3     201       3

DATA RECORDS WRITTEN TO FILE:
 T1_203Z_201Z.DAT

   NST =          1
 NSKIP =          0
  NTIM =       5120


$ COPY   T1_201Z_203Z.DAT T1_SH1_SH3_RECIPROCITY.DAT
$ APPEND T1_203Z_201Z.DAT T1_SH1_SH3_RECIPROCITY.DAT
$!
$ COPY   TC_201Z_203Z.DAT TC_SH1_SH3_RECIPROCITY.DAT
$ APPEND TC_203Z_201Z.DAT TC_SH1_SH3_RECIPROCITY.DAT
$!
$ SET NOVERIFY
```

This procedure constructs a new Tape1 file named T1_SH1_SH3_RECIPROCITY.DAT and a corresponding Coordinate-Code file named TC_SH1_SH3_RECIPROCITY.DAT. Now, plot the 2 data records side-by-side using GO Input file G1F_SH1_SH3_RECIP_DEMO.COM. Execute it the usual manner, as follows:

```
COPY ERA$GO:G1F_SH1_SH3_RECIP_DEMO.COM []

GO G1F_SH1_SH3_RECIP_DEMO
```

Fig. 12-3 shows the resulting plot. The 2 FRFs are identical except for the noise. Note that the correct input-output coordinate codes appear above the plots (201Z+, 203Z+ and 203Z+, 201Z+). ERA cannot analyze this new Tape1 file because it contains data for 2

different excitation locations (ref. Chapter 4). ERA requires each Tape1 file to contain data for only 1 excitation location. Program ERAG1, however, does not enforce this restriction.

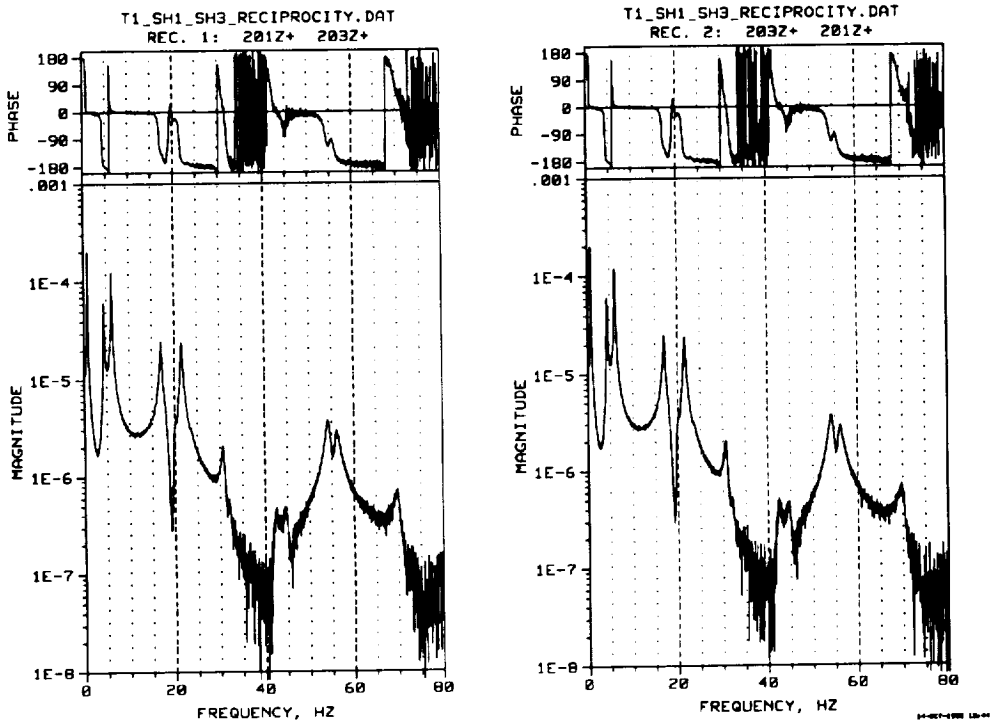


Fig. 12-3. Reciprocity Check Between Driving Points 1 and 3 [G1F_SH1_SH3_RECIP_DEMO]

12.12 Demonstration of ERAG4

Before performing an ERA analysis, it is useful to calculate the average power spectrum (APS) and mode indicator function (MIF) directly from the frequency response data.[237] These functions are defined as follows:

$$APS(f) = \frac{\sum_{i=1}^{N} |H_i(f)|^2}{N} \tag{12-1}$$

$$MIF(f) = \left[1.0 - \frac{\sum_{i=1}^{N} \left| H_i'(f) \right| \left| H_i(f) \right|}{\sum_{i=1}^{N} |H_i(f)|^2} \right] \cdot 1000 \tag{12-2}$$

[237]Only the "scalar" mode indicator function developed in 1973 by Dr. E. Breitbach at DLR (Germany) is available (Refs. 10,11). Multivariate and complex mode indicator functions (Ref. 15) can provide additional information. MIF is also known as the Phase Resonance Criterion (PRC).

where $H_i'(f)$ and $|H_i(f)|$ are the real part and magnitude, respectively, of the ith FRF. N is the total number of FRFs included in the calculation. Both of these functions display peaks at each natural frequency. Additionally, the APS shows the relative magnitude of each modal response. The MIF provides no information concerning modal response magnitudes; however, the resolution of individual modes is much higher.

Warning

The mode indicator function is valid only with frequency response function (FRF) data. With FRFs, the ERA Tape1 data files contain corresponding impulse response functions (IRFs). Each IRF is converted back to an FRF in program ERAG4 using an FFT. If you apply ERAG4 to Tape1 files containing free-decay data for arbitrary initial conditions instead of IRFs, the computed MIF is meaningless. ERAG4 prints a warning message to this effect but it may go unnoticed.

To calculate the APS and MIF for the demonstration problem, first combine the 3 Tape1 files (for Shakers 1, 2, and 3) into a single temporary Tape1 file using the VMS command procedure named BUILD_T1_ALLDATA_DEMO.COM. Copy this file from the ERA$GO directory and execute it as follows:

```
COPY ERA$GO:BUILD_T1_ALLDATA_DEMO.COM []

@BUILD_T1_ALLDATA_DEMO
```

Note that this file is executed with the standard VMS "@" command, not with "GO."

The following information appears on your computer screen when BUILD_T1_ALLDATA_DEMO.COM is run:

```
$ COPY/LOG   ERA$MMST_NAS:T1_MMST_NAS_SH1.DAT T1_MMST_NAS_ALLDATA.DAT
%COPY-S-COPIED, SDBRP$DKA0:[ERA.MMST_NAS]T1_MMST_NAS_SH1.DAT;1 copied to
SDBRP$DKA0:[PAPPA.DEMO]T1_MMST_NAS_ALLDATA.DAT;1 (4169 bloc
ks)
$ APPEND/LOG ERA$MMST_NAS:T1_MMST_NAS_SH2.DAT T1_MMST_NAS_ALLDATA.DAT
%APPEND-S-APPENDED, SDBRP$DKA0:[ERA.MMST_NAS]T1_MMST_NAS_SH2.DAT;1 appended to
SDBRP$DKA0:[PAPPA.DEMO]T1_MMST_NAS_ALLDATA.DAT;1 (114
4 records)
```

```
$ APPEND/LOG ERA$MMST_NAS:T1_MMST_NAS_SH3.DAT T1_MMST_NAS_ALLDATA.DAT
%APPEND-S-APPENDED, SDBRP$DKA0:[ERA.MMST_NAS]T1_MMST_NAS_SH3.DAT;1 appended to
SDBRP$DKA0:[PAPPA.DEMO]T1_MMST_NAS_ALLDATA.DAT;1 (114
4 records)
$ SET NOVERIFY
```

A new Tape1 file named T1_MMST_NAS_ALLDATA.DAT is constructed. *You should delete this file after the results are plotted. It is a large file (12,507 blocks) that will not be used again.*

The APS and MIF functions are calculated with program ERAG4. Copy file G4_DEMO.COM into your current default directory and execute it using GO:

```
COPY ERA$GO:G4_DEMO.COM []

GO G4_DEMO
```

Here is a listing of file G4_DEMO.COM:

```
$! G4_DEMO.COM
$!
$ RUN ERA$EXES:ERAG4
3          PLOT TYPE.  1=AVG. POWER SPECTRUM, 2=MIF, 3=BOTH
T1_MMST_NAS_SH1     TAPE1 FILENAME
1          FIRST RECORD TO INCLUDE IN CALCULATION
1000       LAST  RECORD TO INCLUDE IN CALCULATION (LARGE NO. FOR ALL)
0          HIGHLIGHT EACH DATA PT. ON SPECTRUM WITH A SYMBOL?  1=YES
160        SAMPLING FREQ., HZ
0          DATA FMIN
0          FMIN TO PLOT
80         FMAX TO PLOT
2          DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS
0.0        FREQ. FOR FIRST X-AXIS MINOR TIC MARK.  0.0 = ORIGIN OF PLOT
1          INCLUDE X-AXIS GRID LINES ON PLOT?  1=YES
1          INCLUDE Y-AXIS GRID LINES ON PLOT?  1=YES
1          ADD ADDITIONAL DOTTED VERTICAL LINES AT MINOR TICS?  1=YES
0.35       CHARACTER SIZE IN CM
1          FONT TYPE.  1=STICK
0          PRINT OUT MIF TO FILE G4_MIF.OUT?  1=YES
1          SAVE THE COMPUTED FUNCTIONS IN TAPE1 FORMAT?  1=YES
T1APS_MIF_DEMO     FILE NAME FOR SAVING FUNCTIONS IN TAPE1 FORMAT
0          MODIFY DEFAULT AXIS NUMBERS?  1=YES
```

The following information appears on your computer screen when G4_DEMO is run:

```
ERAG4. PLOT AVG. RESPONSE SPECTRUM OR MODE INDICATOR FUNCTION
       USING TAPE1 DATA

TYPE OF PLOT DESIRED ?  (1)
 1. AVG. POWER SPECTRUM
```

```
 2. MODE INDICATOR FUNCTION
 3. BOTH, IN TOP/BOTTOM FORMAT
          3

WARNING: MIF CALCULATION IS VALID ONLY WITH
IRF DATA (I.E., NOT WITH ARBITRARY FREE-DECAY DATA).

TAPE1 FILENAME ? [DEFAULT FILE TYPE = .DAT]
T1_MMST_NAS_ALLDATA.DAT


THERE ARE  312 DATA RECORDS IN THIS FILE.
EACH RECORD HAS  5120 DATA POINTS.

ENTER FIRST RECORD NO. TO INCLUDE IN CALCULATION ?  (1)
          1

ENTER LAST RECORD NO. TO PLOT ?  ( 312)
[ENTER A LARGE NUMBER TO USE ALL AVAILABLE DATA]
      10000

SELECT SCALING METHOD FOR TIME TO FREQ. FFT:  (1)
 1. MULTIPLY BY DT (TO CONVERT IRF TO FRF)
 2. DIVIDE BY N (TO OBTAIN CORRECT SINE WAVE AMPL. INDEPENDENT OF
     RECORD LENGTH
          1

HIGHLIGHT EACH DATA PT. ON PLOT WITH A SYMBOL ?  1=YES.  (0)
          0

ENTER SF [SAMPLING FREQUENCY IN HERTZ] ?  (100.)
  160.0000

DATA FMIN ? [> 0 FOR ZOOMED DATA]  (0.)
 0.0000000E+00

FMIN TO PLOT ?       0.000)
 0.0000000E+00

FMAX TO PLOT ? (    80.00)
  80.00000

DELTA FREQ. (HZ) FOR X-AXIS MINOR TIC MARKS ? 0=NONE  (1.0)
  2.000000

FREQ. OF FIRST X-AXIS MINOR TIC MARK ?  0.0 = ORIGIN OF PLOT. (0.0)
 0.0000000E+00

INCLUDE X-AXIS GRID LINES ON THE PLOT
(AT EACH MAJOR TIC) ?  1=YES  (1)
          1

INCLUDE Y-AXIS GRID LINES ON THE PLOT
(AT EACH MAJOR TIC) ?  1=YES  (1)
```

```
          1

ALSO ADD ADDITIONAL DOTTED VERTICAL LINES AT MINOR TIC MARKS ?  1=YES.  (1)
          1

CHARACTER SIZE (HT.) FOR PLOT LABELS, IN CM ?  (0.3)
 0.3500000

FONT TYPE ?  (1)
 1 = STICK FONT
 2 = LETTER QUALITY - BOLD
 3 = LETTER QUALITY - STD.
          1

PRINT OUT MIF FUNCTION TO FILE G4_MIF.OUT ? [1=YES]  (0)
          0

SAVE THE COMPUTED FUNCTIONS IN TAPE1 FORMAT ? 1=YES  (0)
          1

FILENAME FOR STORING COMPUTED FUNCTIONS IN TAPE1 FORMAT ?
[DEFAULT FILE TYPE = .DAT]
T1APS_MIF_DEMO.DAT


MODIFY DEFAULT AXIS NUMBERS ?  1=YES  (0)
          0

GRAPHICS DEVICE NUMBER ?  (4)
  1 = TEK. 4010
  2 = TEK. 4014
  3 = TEK. 4025
  4 = TEK. 4107
  5 = TEK. 4115B
  6 = HP 2647/2648
  7 = DEC VT240
  8 = HPGL TALL
  9 = HPGL WIDE
 10 = POSTSCRIPT TALL
 11 = POSTSCRIPT WIDE

          4

 READING IN DATA ...

 NS =   10
 NS =   20
 NS =   30
 NS =   40
 NS =   50
 NS =   60
 NS =   70
 NS =   80
 NS =   90
```

```
NS =  100
NS =  110
NS =  120
NS =  130
NS =  140
NS =  150
NS =  160
NS =  170
NS =  180
NS =  190
NS =  200
NS =  210
NS =  220
NS =  230
NS =  240
NS =  250
NS =  260
NS =  270
NS =  280
NS =  290
NS =  300
NS =  310
```

Note: When running G4_DEMO.COM, there is a considerable pause (10 sec. on the author's VAXstation 3100) after the Tape1 file name is printed on the computer screen. This pause occurs as ERAG4 determines the number of data records in the file. Approximately 3 minutes of additional CPU time are necessary to compute the APS and MIF functions. Progress is reported every 10 data records.

Fig. 12-4 shows the resulting APS and MIF functions for this demonstration problem.

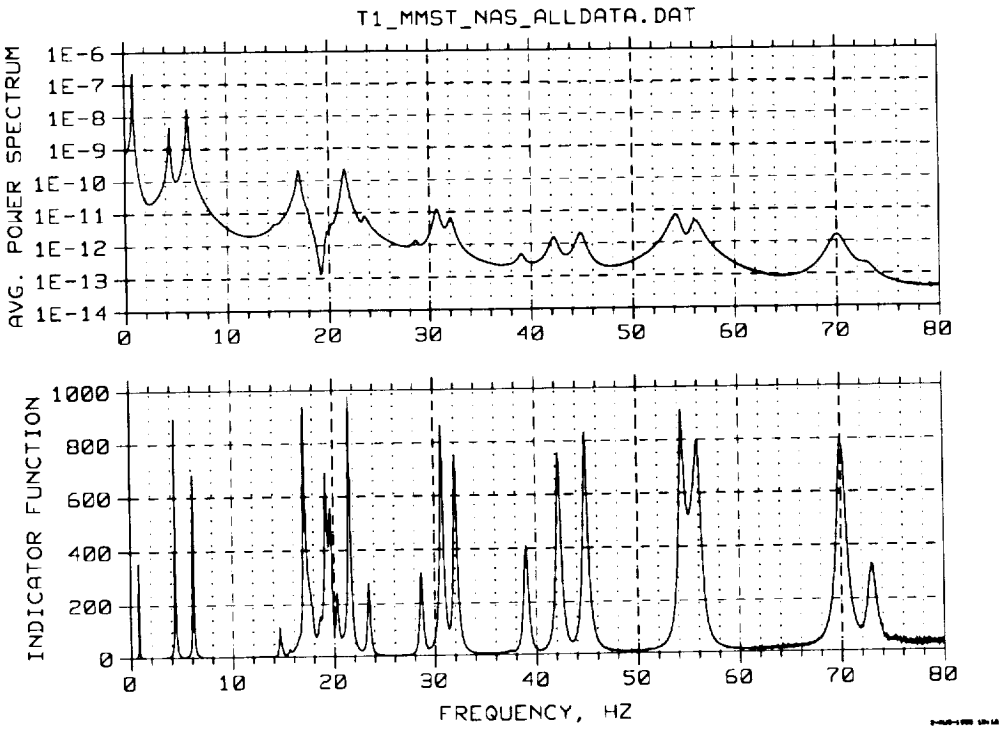


Fig. 12-4. Average Power Spectrum and Mode Indicator Function

12.13 NASTRAN Natural Frequencies of Mini-Mast Demonstration Problem

Because the demonstration problem uses simulated data, the correct modal parameters of the "test structure" are known. You can compare the correct natural frequencies with the peaks in the APS and MIF functions shown in Fig. 12-4. A list of these frequencies is available by creating an index of the NASTRAN mode shapes contained in file MMST_NASEIGV_900110_TESTDOFS.UNV (universal file format). This file is stored in directory ERA$MMST_NAS. Pre-processor program ERAP26 (Option 8) is available this purpose.

Copy GO input file P26_8_DEMO.COM from directory ERA$GO to your current default directory and execute it using GO. You obtain a list of natural frequencies as follows:

NO.	CASE NO.	EIGENVALUE NO.	FREQ.,HZ	ZETA,%	CMI,%
1:	0	1	0.798	0.000	0.00
2:	0	2	0.800	0.000	0.00
3:	0	3	4.369	0.000	0.00
4:	0	4	6.106	0.000	0.00
5:	0	5	6.159	0.000	0.00
6:	0	6	14.615	0.000	0.00
7:	0	7	14.815	0.000	0.00
8:	0	8	14.962	0.000	0.00

9:	0	9	15.568	0.000	0.00
10:	0	10	15.600	0.000	0.00
11:	0	11	15.830	0.000	0.00
12:	0	12	15.883	0.000	0.00
13:	0	13	16.086	0.000	0.00
14:	0	14	16.105	0.000	0.00
15:	0	15	16.281	0.000	0.00
16:	0	16	16.296	0.000	0.00
17:	0	17	16.451	0.000	0.00
18:	0	18	16.507	0.000	0.00
19:	0	19	16.584	0.000	0.00
20:	0	20	16.591	0.000	0.00
21:	0	21	16.651	0.000	0.00
22:	0	22	16.665	0.000	0.00
23:	0	23	16.682	0.000	0.00
24:	0	24	16.689	0.000	0.00
25:	0	25	16.804	0.000	0.00
26:	0	26	16.807	0.000	0.00
27:	0	27	16.921	0.000	0.00
28:	0	28	16.940	0.000	0.00
29:	0	29	16.981	0.000	0.00
30:	0	30	17.008	0.000	0.00
31:	0	31	17.018	0.000	0.00
32:	0	32	17.029	0.000	0.00
33:	0	33	17.050	0.000	0.00
34:	0	34	17.065	0.000	0.00
35:	0	35	17.142	0.000	0.00
36:	0	36	17.153	0.000	0.00
37:	0	37	17.154	0.000	0.00
38:	0	38	17.205	0.000	0.00
39:	0	39	17.277	0.000	0.00
40:	0	40	17.317	0.000	0.00
41:	0	41	17.319	0.000	0.00
42:	0	42	17.323	0.000	0.00
43:	0	43	17.341	0.000	0.00
44:	0	44	17.344	0.000	0.00
45:	0	45	17.383	0.000	0.00
46:	0	46	17.395	0.000	0.00
47:	0	47	17.400	0.000	0.00
48:	0	48	17.425	0.000	0.00
49:	0	49	17.464	0.000	0.00
50:	0	50	17.467	0.000	0.00
51:	0	51	17.473	0.000	0.00
52:	0	52	17.478	0.000	0.00
53:	0	53	17.496	0.000	0.00
54:	0	54	17.542	0.000	0.00
55:	0	55	17.552	0.000	0.00
56:	0	56	17.585	0.000	0.00
57:	0	57	17.611	0.000	0.00
58:	0	58	17.625	0.000	0.00
59:	0	59	17.654	0.000	0.00
60:	0	60	17.675	0.000	0.00
61:	0	61	17.680	0.000	0.00
62:	0	62	17.687	0.000	0.00

63:	0	63	17.693	0.000	0.00
64:	0	64	17.715	0.000	0.00
65:	0	65	17.726	0.000	0.00
66:	0	66	17.763	0.000	0.00
67:	0	67	17.767	0.000	0.00
68:	0	68	17.803	0.000	0.00
69:	0	69	17.805	0.000	0.00
70:	0	70	17.812	0.000	0.00
71:	0	71	17.819	0.000	0.00
72:	0	72	17.824	0.000	0.00
73:	0	73	17.844	0.000	0.00
74:	0	74	17.860	0.000	0.00
75:	0	75	17.876	0.000	0.00
76:	0	76	17.899	0.000	0.00
77:	0	77	17.951	0.000	0.00
78:	0	78	18.002	0.000	0.00
79:	0	79	18.032	0.000	0.00
80:	0	80	18.049	0.000	0.00
81:	0	81	18.059	0.000	0.00
82:	0	82	18.066	0.000	0.00
83:	0	83	18.163	0.000	0.00
84:	0	84	18.172	0.000	0.00
85:	0	85	18.178	0.000	0.00
86:	0	86	18.241	0.000	0.00
87:	0	87	18.255	0.000	0.00
88:	0	88	18.304	0.000	0.00
89:	0	89	18.325	0.000	0.00
90:	0	90	18.351	0.000	0.00
91:	0	91	18.379	0.000	0.00
92:	0	92	18.414	0.000	0.00
93:	0	93	18.441	0.000	0.00
94:	0	94	18.452	0.000	0.00
95:	0	95	18.528	0.000	0.00
96:	0	96	18.567	0.000	0.00
97:	0	97	18.596	0.000	0.00
98:	0	98	18.614	0.000	0.00
99:	0	99	18.677	0.000	0.00
100:	0	100	18.698	0.000	0.00
101:	0	101	18.750	0.000	0.00
102:	0	102	18.754	0.000	0.00
103:	0	103	18.837	0.000	0.00
104:	0	104	18.870	0.000	0.00
105:	0	105	18.874	0.000	0.00
106:	0	106	18.917	0.000	0.00
107:	0	107	18.945	0.000	0.00
108:	0	108	18.949	0.000	0.00
109:	0	109	18.959	0.000	0.00
110:	0	110	18.986	0.000	0.00
111:	0	111	18.990	0.000	0.00
112:	0	112	19.061	0.000	0.00
113:	0	113	19.389	0.000	0.00
114:	0	114	19.392	0.000	0.00
115:	0	115	19.729	0.000	0.00
116:	0	116	19.746	0.000	0.00

117:	0	117	20.308	0.000	0.00
118:	0	118	21.570	0.000	0.00
119:	0	119	23.474	0.000	0.00
120:	0	120	28.648	0.000	0.00
121:	0	121	30.721	0.000	0.00
122:	0	122	32.064	0.000	0.00
123:	0	123	37.335	0.000	0.00
124:	0	124	38.309	0.000	0.00
125:	0	125	38.322	0.000	0.00
126:	0	126	38.322	0.000	0.00
127:	0	127	39.012	0.000	0.00
128:	0	128	42.222	0.000	0.00
129:	0	129	44.856	0.000	0.00
130:	0	130	54.267	0.000	0.00
131:	0	131	56.054	0.000	0.00
132:	0	132	56.328	0.000	0.00
133:	0	133	56.336	0.000	0.00
134:	0	134	69.867	0.000	0.00
135:	0	135	70.183	0.000	0.00
136:	0	136	72.523	0.000	0.00
137:	0	137	72.874	0.000	0.00
138:	0	138	72.933	0.000	0.00
139:	0	139	72.946	0.000	0.00
140:	0	140	75.196	0.000	0.00
141:	0	141	84.348	0.000	0.00
142:	0	142	87.667	0.000	0.00
143:	0	143	87.670	0.000	0.00
144:	0	144	88.140	0.000	0.00
145:	0	145	89.103	0.000	0.00
146:	0	146	91.590	0.000	0.00
147:	0	147	93.833	0.000	0.00
148:	0	148	95.271	0.000	0.00
149:	0	149	95.482	0.000	0.00
150:	0	150	98.427	0.000	0.00
151:	0	151	98.761	0.000	0.00
152:	0	152	99.129	0.000	0.00
153:	0	153	99.240	0.000	0.00

These are the 153 NASTRAN-predicted modes of the Mini-Mast structure below 100 Hz used to construct the frequency response functions for this demonstration problem.

With NASTRAN modes, the data in columns 2, 5, and 6 (case no., damping factor, and CMI) are unavailable. When applied to experimental mode shape results, however (such as to file 88INIT_20_50.UNV generated in Section 3.5), these columns will contain meaningful information.

APPENDIX A - SOFTWARE INSTALLATION

The software is usually delivered as a VAX/VMS BACKUP Saveset copied onto a 6250 bpi magnetic tape or TK50 cartridge. Copy this file from the tape to a file named ERA.BCK in your login directory. Next, SET DEFAULT to the directory into which ERA is to be installed, preferably a root directory named [ERA].[238] If this directory contains a previous version of the software, delete these old files before proceeding. Then, enter the following command to load [ERA] and all subdirectories:

```
BACKUP/LOG SYS$LOGIN:ERA.BCK/SAVE/SEL=[ERA...]*.*;* [...]*.*;*
```

The only file requiring modification is [ERA]SUERA.COM. SUERA is an acronym for "Set Up ERA." This file is listed below. Six changes are necessary to specify site-specific information. These changes are highlighted in bold type.

```
$!
$! SUERA.COM: SET UP ERA
$!
$! USAGE:
$!  @[ERA]SUERA                    : To access local copy of ERA
$!  @[ERA]SUERA REMOTE             : To access ERA remotely over DECNET
$!                                    (Note: PROXY Access required for
$!                                           remote access.)
$!
$ ASSIGN NL: SYS$OUTPUT
$ ASSIGN NL: SYS$ERROR
$! ON ERROR THEN EXIT
$!
$ IF P1 .EQS. "REMOTE" THEN GOTO REMOTE_USER
$!
$    DEFINE  ERA$DISK  SDBRP$DKA0:  ! ATTENTION SYSTEM MANAGER:
$!     *** Modify definition of ERA$DISK during installation.
$!         ERA$DISK is the disk on which [ERA...] is installed.
$!
$  DEFINE ERA ERA$COMS:ERA.COM
$!
$  GOTO CONTINUE1
$!
$ REMOTE_USER:
$!
$    DEFINE  ERA$DISK  SDBRP::SDBRP$DKA0:  ! ATTENTION SYSTEM MANAGER:
$!     *** Modify definition of ERA$DISK during installation.
$!         ERA$DISK is the disk on which [ERA...] is installed.
$!
```

[238]The software can also be installed under another directory, e.g., under your personal user directory. See additional comments following the listing of SUERA.COM.

```
$  DEFINE ERA SYS$LOGIN:ERA.COM
$  DELETE SYS$LOGIN:ERA.COM;*
$  COPY ERA$DISK:[ERA.COMS]ERA.COM SYS$LOGIN:
$!
$  WRITE SYS$OUTPUT ""
$  SYM_ERA_DISK = F$TRNLNM("ERA$DISK")
$  WRITE SYS$OUTPUT -
"Remote access to ERA on ",SYM_ERA_DISK," has been established."
$!
$ CONTINUE1:
$!
$ DEFINE ERA$ ERA$DISK:[ERA]
$!
$ DEFINE ERA$COMS        ERA$DISK:[ERA.COMS]
$ DEFINE ERA$DIGLIB      ERA$DISK:[ERA.DIGLIB]
$ DEFINE ERA$EXES        ERA$DISK:[ERA.EXES]
$ DEFINE ERA$GO          ERA$DISK:[ERA.GO]
$ DEFINE ERA$HELP        ERA$DISK:[ERA.HELP]
$ DEFINE ERA$LW          ERA$DISK:[ERA.LW]
$ DEFINE ERA$MATLAB      ERA$DISK:[ERA.MATLAB]
$ DEFINE ERA$MISC        ERA$DISK:[ERA.MISC]
$ DEFINE ERA$MMST_NAS    ERA$DISK:[ERA.MMST_NAS]
$ DEFINE ERA$MPLUS       ERA$DISK:[ERA.MPLUS]
$ DEFINE ERA$MX          ERA$DISK:[ERA.MX]
$ DEFINE ERA$NONVAX      ERA$DISK:[ERA.NONVAX_USAGE]
$ DEFINE ERA$OBJS        ERA$DISK:[ERA.OBJS]
$ DEFINE ERA$OEXS        ERA$DISK:[ERA.OTHER_EXAMPLES]
$ DEFINE ERA$OPTIONS     ERA$DISK:[ERA.OPTIONS]
$ DEFINE ERA$QA          ERA$DISK:[ERA.QA]
$ DEFINE ERA$SOURCES     ERA$DISK:[ERA.SOURCES]
$ DEFINE ERA$TEMP        ERA$DISK:[ERA.TEMP]
$ DEFINE ERA$TESTCASES   ERA$DISK:[ERA.TESTCASES]
$ DEFINE ERA$UG          ERA$DISK:[ERA.UG]
$ DEFINE ERA$USER_GO     []
$ DEFINE ERA$USERS       ERA$DISK:[ERA.USERS]
$ DEFINE ERA$UTIL        ERA$DISK:[ERA.UTIL]
$ DEFINE ERA$2DOF        ERA$DISK:[ERA.2DOF]
$!
$  DEFINE  ERA_BATCH_QUEUE  SYS$BATCH  !  ATTENTION  SYSTEM  MANAGER:
$!     ***  Modify  definition  of  ERA_BATCH_QUEUE  during  installation.
$!          ERA_BATCH_QUEUE  is  the  queue  to  which  ERA  batch  jobs  are  sent.
$!
$ ERA :== @ERA$COMS:SUBMIT_ERA.COM
$!
$ SPNERA :== SPAWN/OUT=NL:/INP=NL:/NOTIFY/NOWAIT @ERA
$!
$! ABBREVIATION FOR RUNNING QA CHECKS
$!
$ QA_ERA :== SUBMIT/NOTIFY/NOLOG/NOPRINT ERA$COMS:QA_ERA.COM
$!
$! ABBREVIATION FOR RUNNING PP EXECUTIVE
$!
$ ERAPP  :== @ERA$COMS:ERAPP.COM
$!
```

```
$! ABBREVIATIONS FOR PRE- AND POST-PROCESSORS
$!
$ ERAP0  :== $ERA$EXES:ERAP0
$ ERAP0B :== $ERA$EXES:ERAP0B
$ ERAP1  :== $ERA$EXES:ERAP1
$ ERAP1B :== $ERA$EXES:ERAP1B
$ ERAP2  :== $ERA$EXES:ERAP2
$ ERAP2B :== $ERA$EXES:ERAP2B
$ ERAP2C :== $ERA$EXES:ERAP2C
$ ERAP2D :== $ERA$EXES:ERAP2D
$ ERAP3  :== $ERA$EXES:ERAP3
$ ERAP3B :== $ERA$EXES:ERAP3B
$ ERAP3C :== $ERA$EXES:ERAP3C
$ ERAP4  :== $ERA$EXES:ERAP4
$ ERAP5  :== $ERA$EXES:ERAP5
$ ERAP6  :== $ERA$EXES:ERAP6
$ ERAP9  :== $ERA$EXES:ERAP9
$ ERAP10 :== $ERA$EXES:ERAP10
$ ERAP10B :== $ERA$EXES:ERAP10B
$ ERAP10C :== $ERA$EXES:ERAP10C
$ ERAP11 :== $ERA$EXES:ERAP11
$ ERAP20 :== $ERA$EXES:ERAP20
$ ERAP21 :== $ERA$EXES:ERAP21
$ ERAP24 :== $ERA$EXES:ERAP24
$ ERAP24B :== $ERA$EXES:ERAP24B
$ ERAP25 :== $ERA$EXES:ERAP25
$ ERAP26 :== $ERA$EXES:ERAP26
$ ERAP27 :== $ERA$EXES:ERAP27
$ ERAP30 :== $ERA$EXES:ERAP30
$ ERAP40 :== $ERA$EXES:ERAP40
$ ERAP70 :== $ERA$EXES:ERAP70
$ ERAP75A :== $ERA$EXES:ERAP75A
$ ERAP75B :== $ERA$EXES:ERAP75B
$ ERAP76A :== $ERA$EXES:ERAP76A
$ ERAP76B :== $ERA$EXES:ERAP76B
$ ERAP76C :== $ERA$EXES:ERAP76C
$ ERAP79 :== $ERA$EXES:ERAP79
$ ERAP80 :== $ERA$EXES:ERAP80
$ ERAP81 :== $ERA$EXES:ERAP81
$ ERAP82 :== $ERA$EXES:ERAP82
$ ERAP85 :== $ERA$EXES:ERAP85
$ ERAP85B :== $ERA$EXES:ERAP85B
$ ERAP88 :== $ERA$EXES:ERAP88
$ ERAP89 :== $ERA$EXES:ERAP89
$ ERAP89B:== $ERA$EXES:ERAP89B
$ ERAP90 :== $ERA$EXES:ERAP90
$ ERAP91 :== $ERA$EXES:ERAP91
$ ERAP92 :== $ERA$EXES:ERAP92
$ ERAP98 :== $ERA$EXES:ERAP98
$ ERAP99 :== $ERA$EXES:ERAP99
$ ERAP125:== $ERA$EXES:ERAP125
$!
$! GRAPHICS
$!
```

```
$ ERAG1   :== @ERA$COMS:RUN_ERAG1
$ ERAG1B  :== @ERA$COMS:RUN_ERAG1B
$ ERAG2   :== @ERA$COMS:RUN_ERAG2
$ ERAG2B  :== @ERA$COMS:RUN_ERAG2B
$ ERAG2C  :== @ERA$COMS:RUN_ERAG2C
$ ERAG3   :== @ERA$COMS:RUN_ERAG3
$ ERAG3B  :== @ERA$COMS:RUN_ERAG3B
$ ERAG4   :== @ERA$COMS:RUN_ERAG4
$ ERAG5   :== @ERA$COMS:RUN_ERAG5
$ ERAG5B  :== @ERA$COMS:RUN_ERAG5B
$ ERAG6   :== @ERA$COMS:RUN_ERAG6
$ ERAG7   :== @ERA$COMS:RUN_ERAG7
$ ERAG7B  :== @ERA$COMS:RUN_ERAG7B
$ ERAG10  :== @ERA$COMS:RUN_ERAG10
$ ERAG15  :== @ERA$COMS:RUN_ERAG15
$ ERAG25  :== @ERA$COMS:RUN_ERAG25
$ ERAG26  :== @ERA$COMS:RUN_ERAG26
$ ERAG50  :== @ERA$COMS:RUN_ERAG50
$ ERAG92  :== @ERA$COMS:RUN_ERAG92
$!
$! ABBREVIATIONS FOR RUNNING PP'S WITH COMMAND-FILE INPUT DATA
$!
$ GO      :== @ERA$COMS:GO_CNTRL
$ GODEMO  :== @ERA$COMS:GODEMO_CNTRL
$!
$! MISC.
$!
$ AVG_SPECTRUM_MAG :== $ERA$EXES:AVG_SPECTRUM_MAG
$ BATCHBB     :== @ERA$UTIL:BATCHBB.COM
$ BATCHRP     :== @ERA$UTIL:BATCHRP.COM
$ BBBATCH     :== DEFINE ERA_BATCH_QUEUE SYS$BATCH
$ DELPS       :== @ERA$UTIL:DELPS.COM
$ ET          :== $ERA$EXES:ET
$ HERA        :== HELP @ERA ERA
$ LW80        :== @ERA$LW:LW80_CNTRL.COM
$ LW80DS      :== @ERA$LW:LW80DS_CNTRL.COM
$ LW80NF      :== @ERA$LW:LW80_NO_FOOTER_CNTRL.COM
$ LW132       :== @ERA$LW:LW132_CNTRL.COM
$ LW132UG     :== @ERA$LW:LW132UG_CNTRL.COM
$ LW2COLS     :== @ERA$LW:LW2COLS_CNTRL.COM
$ LWP         :== @ERA$LW:LWP.COM
$ LWPICS      :== @ERA$LW:LWPICS.COM
$ LWPICS0     :== @ERA$LW:LWPICS0.COM
$ MIMO        :== $ERA$EXES:MIMO
$ PSHR        :== @ERA$UTIL:PSHR.COM
$ PSNY        :== @ERA$UTIL:PSNY.COM
$ PSRSM       :== @ERA$UTIL:PSRSM.COM
$ PSVB        :== @ERA$UTIL:PSVB.COM
$ PUG         :== @ERA$UG:PUG.COM
$!
$ RELOAD_ERA :== @SYS$LOGIN:RELOAD_ERA.COM
$!
$ RESET99     :== @ERA$COMS:RESET99
$ RPBATCH     :== DEFINE ERA_BATCH_QUEUE SYS$RPBATCH
```

```
$ SAVEPS      :== @ERA$UTIL:SAVEPS.COM
$ SDGO        :== @ERA$UTIL:SDGO.COM
$ SISO        :== $ERA$EXES:SISO
$!
$ TDVI        :== @ERA$UG:TDVI.COM
$ TDVIF       :== @ERA$UG:TDVIF.COM
$ TPRE        :== @ERA$UG:TPRE.COM
$ TV          :== TYPE ERA$:VERSION
$!
$! ----------------------
$! SET UP USER PREFERENCES
$!
$! DEFAULT VALUES:
$!
$  DEFINE  PS_OUTPUT_DEVICE  SDBNY::CSA0:  ! ATTENTION SYSTEM MANAGER:
$!    *** Modify definition of PS_OUTPUT_DEVICE during installation.
$!         PS_OUTPUT_DEVICE is the printer to which PostScript plots
$!         and listings are sent.
$!
$ DEASSIGN SYS$OUTPUT
$ DEASSIGN SYS$ERROR
$!
$  PS_HARDCOPY_COMMAND:==COPY       ! ATTENTION SYSTEM MANAGER
$!  PS_HARDCOPY_COMMAND:==PRINT    ! PS_HARDCOPY_COMMAND:== COPY or PRINT
$!                            to select command used to print PostScript files
$!                                  (COPY to device PS_OUTPUT_DEVICE or
$!                                   PRINT to queue PS_OUTPUT_DEVICE)
$!
$!
$ LWP_DELETE_PS :== YES
$!
$! EACH USER CAN CHANGE THE ABOVE DEFAULTS BY PLACING
$! REDEFINITIONS IN FILE SYS$LOGIN:SUERA_USER.COM;
$!
$ ON ERROR THEN CONTINUE
$ @SYS$LOGIN:SUERA_USER.COM
$ ON ERROR THEN EXIT
$! ----------------------
$!
$! INITIALIZE DIGLIB FONTS
$!
$ @ERA$COMS:VAXFONTS
$!
$! RESET LU99 & DELETE LOGICAL NAME TABLE ERA (IF LEFT
$! FROM A PREVIOUS ABORTED INTERCATIVE RUN)
$!
$ RESET99
$!
$ WRITE SYS$OUTPUT ""
$ TYPE ERA$:VERSION
$ WRITE SYS$OUTPUT " installed."
$ WRITE SYS$OUTPUT ""
$!
$! SEND NEWS TO ALL USERS
$!
```

```
$  TYPE  ERA$:NEWS_TO_ALL_USERS  !  ATTENTION  SYSTEM  MANAGER:
$!  Put  news  messages  to  all  users  in  file  ERA$:NEWS_TO_ALL_USERS.LIS.
$!
$ EXIT
```

As mentioned above in a footnote, the software can be installed under another directory such as your personal user directory (rather than in a root directory named [ERA]). In this situation, the following definition of ERA$DISK is necessary in SUERA.COM:

```
DEFINE/PROCESS/NOLOG/TRANS=(TERMI,CONCE) ERA$DISK DISK$NAME:[MY_DIR.]
```

where DISK$NAME is the disk on which the software is installed and [MY_DIR] is the directory under which [ERA...] is placed.

APPENDIX B - COMPUTER-SPECIFIC PARAMETERS

```
      BLOCK DATA SPARAM
C
C     FILE ERASYS.FOR
C
C      SET SYSTEM-DEPENDENT PARAMETERS FOR ERA
C
C      R.PAPPA
C
      COMMON /ERASYS/ BIGPOS,BIGNEG,ESMALL,ELARGE,SMLLSV,TOL,IXZTST,
     $                RADIX,IXMACH,R1DETF,R2DETF,EPS
C
C
C      FOR USE ON VAX IN 32-BIT SINGLE PRECISION, SET:
C      -----------------------------------------------
CVX   DATA BIGPOS/1.0E16/
CVX   DATA BIGNEG/-1.0E16/
CVX   DATA ESMALL/-80./
CVX   DATA ELARGE/80./
CVX   DATA SMLLSV/1.0E-8/
CVX   DATA EPS/5.961E-8/
C
C      EPS is the same as MACHEP defined below.  Its value can be
C      determined by running program [ERA.SOURCES]EPS.FOR
C
C      ALSO, THE FOLLOWING VALUES ARE USED IN THE SCIENTIFIC
C      LIBRARY SUBROUTINES:
C
C      IN GIASOS:
C
CVX   DATA TOL/5.0E-32/
CVX   DATA IXZTST/-23/
C
C      IN QXZ146 (BALANC):
C
CVX   DATA RADIX/2.0/
C
C      IN QXZ149 (HQR2):
C
C       MACHEP = 2**IXMACH,
C        MACHEP is the smallest positive working precision floating-point
C        number which, when added to 1.0 using the working precision
C        addition operation, gives a number larger than 1.0
C
CVX   DATA IXMACH/-23/
C
C      IN DETFAC:
C
CVX   DATA R1DETF/1.0E38/
CVX   DATA R2DETF/1.0E-38/
```

```
C
C
C       FOR USE ON CDC 60-BIT COMPUTERS, SET:
C       ------------------------------------
CDC   DATA BIGPOS/1.0E50/
CDC   DATA BIGNEG/-1.0E50/
CDC   DATA ESMALL/-675./
CDC   DATA ELARGE/100./
CDC   DATA SMLLSV/1.0E-15/
C   *** WARNING  ... EPS TBD: ...
CDC   DATA EPS/-999./
C
C       IN GIASOS:
C
CDC   DATA TOL/1.0E-60/
CDC   DATA IXZTST/-48/
C
C       IN QXZ146 (BALANC):
C
CDC   DATA RADIX/2.0/
C
C       IN QXZ149 (HQR2):
C
CDC   DATA IXMACH/-47/
C
C       IN DETFAC:
C
CDC   DATA R1DETF/1.0E100/
CDC   DATA R2DETF/1.0E-100/
C
      END
```

APPENDIX C - ERROR MESSAGES

```
* * *
* * *  THIS IS FILE ERA$HELP:ERROR_MESSAGES.LIS:
* * *   FATAL AND WARNING ERROR MESSAGES FOR ERA
* * *
* * *   R.PAPPA
* * *
.F
000
AT LEAST ONE OF THE FOLLOWING ANALYSIS PARAMETERS WAS NEGATIVE OR ZERO: NRH, NCH, NST, NIC, NTIM, N2, OR N3.  ALL
OF THEM MUST BE POSITIVE.
.F
001
NSKIP CANNOT BE LESS THAN ZERO.
.F
002
ARRAY DIMENSION MRH IS TOO SMALL.  IT MUST BE NO SMALLER THAN NRH.
.F
003
ARRAY DIMENSION MCH IS TOO SMALL.  IT MUST BE NO SMALLER THAN NCH.
.F
004
ARRAY DIMENSION MST IS TOO SMALL.  IT MUST BE NO SMALLER THAN NST, WHICH IS EQUAL TO NSLAST-NSFRST-1.
.F
005
ARRAY DIMENSION MIC IS TOO SMALL.  IT MUST BE NO SMALLER THAN NIC.
.F
006
ARRAY DIMENSION MTIM IS TOO SMALL.  IT MUST BE NO SMALLER THAN NTIM.
(I.E., INSUFFICIENT DATA POINTS ARE AVAILABLE IN THE TAPE1 DATA FILE (MTIM)
TO PERFORM THE REQUESTED ANALYSIS WHICH REQUIRES NTIM DATA POINTS.)
SEE MESSAGE ABOVE FOR ADDITIONAL INFORMATION.
.F
007
N1 CANNOT BE ZERO
.F
008
NUMBER OF DECLARED TAPE1 FILES IN USER INPUT FILE IS LESS THAN NIC.
.F
009
A MEMORY CONFLICT OCCURS WITH TEMPORARY STORAGE SINCE NI IS LARGER THAN MSHORT. MAKE MSHORT = MIN(MRH,MCH) AT LEAST
AS LARGE AS NIC.
.F
010
SAMPLING FREQUENCY, SF, MUST BE A POSITIVE NUMBER.
.F
011
UNUSED
.F
012
THIS ERROR MESSAGE NOT ASSIGNED
.F
013
NST=NSLAST-NSFRST+1 CAN BE NO LARGER THAN MST
.F
014
TAPE1 FILE NAME DOES NOT BEGIN WITH T1
.F
015
NONE OF THE ELEMENTS OF THE NSFLAG() ARRAY WERE SET TO 1.  WHEN NRH IS > NST, AT LEAST 1 ELEMENT OF NSFLAG() MUST
BE 1.
.F
016
IERR RETURNED FROM SUBROUTINE GIASOS WAS > 0.  UNABLE TO ACHIEVE CONVERGENCE IN 100 ITERATIONS.
.F
017
IERR RETURNED FROM SUBROUTINE REQRME WAS <> 0.  SEE REQRME (REQR) DOCUMENTATION FOR MORE INFORMATION.
.F
018
IERR RETURNED FROM SUBROUTINE GELIM WAS <> 0.  SEE GELIM DOCUMENTATION FOR MORE INFORMATION.
.F
019
REQUESTED IOPT NO. IS OUTSIDE THE RANGE OF AVAILABLE CHOICES.
.F
020
NAMELIST &ERAPAR WAS EMPTY.  A VALUE FOR AT LEAST THE PARAMETER SF MUST BE ENTERED.
.F
021
YOU NEED TO SUPPLY A VALUE FOR IPAR1.
.F
022
YOU NEED TO SUPPLY A VALUE FOR IPAR2.
.F
023
YOU NEED TO SUPPLY A VALUE FOR IPAR3.
```

```
.F
024
YOU NEED TO SUPPLY A VALUE FOR IPAR4.
.F
025
YOU NEED TO SUPPLY A VALUE FOR IPAR5.
.F
026
AN INCONSISTENT REFERENCE COORDINATE WAS DETECTED IN ONE OF THE
COORDINATE CODE FILES.
.F
027
AN INCONSISTENT RESPONSE COORDINATE WAS DETECTED IN ONE OF THE
COORDINATE CODE FILES.
.F
028
MST EXCEEDED 750.  THE SIZE OF ARRAY NSFLAG(750) NEEDS TO BE INCREASED.
.F
029
UNUSED
.F
030
ITYDTA IS LESS THAN ZERO OR GREATER THAN 3.  THIS PARAMETER IS USED IN COMPUTING THE RESIDUE VALUE APPEARING IN THE
MODAL-PLUS PARAMETER TABLE.  SET ITYDTA=1 FOR D/F DATA, =2 FOR V/F DATA, AND =3 FOR A/F DATA.
.F
031
IREFTU MUST BE BETWEEN 0 AND NIC, THE NO. OF INITIAL CONDITIONS.
.F
032
DATABW MUST BE > 0.0
.F
033
DATABW CAN BE NO LARGER THAN SF/2.
.F
034
A NON-POSITIVE COORDINATE LOCATION WAS DETECTED.  PUT THE NEGATIVE SIGN ON THE COORDINATE SENSE INSTEAD OF ON THE
COORDINATE LOCATION NO.
.F
035
A COORDINATE LOCATION NUMBER WITH MORE THAN 6 DIGITS WAS DETECTED. (INCOMPATIBLE WITH CURRENT FORMAT STATEMENTS IN
ERA.)
.F
036
ILLEGAL COORDINATE DIRECTION DETECTED.  DIRECTION MUST BE +/-1,+/-2,+/-3,+/-4,+/-5, OR +/-6
.F
037
ISTRIP MUST BE A POSITIVE NUMBER.
.F
038
PAR(1), PAR(2), AND PAR(3) ARE INCONSISTENT; E.G. PAR(2)<PAR(1) BUT PAR(3)>0
.F
039
ILLEGAL VALUE IN KEYDTA().  ALL VALUES MUST BE BETWEEN 1 AND MST.
.F
040
ILLEGAL VALUE IN ITAPES().  ALL VALUES MUST BE BETWEEN 50 AND 98.
.F
041
IORDTU MUST BE BETWEEN 1 AND IORDR0=MIN(NRH,NCH).
.F
042
SINGULAR-VALUE CUTOFF TOO HIGH.  ATTEMPTED TO RETAIN A ZERO-VALUED SINGULAR VALUE.
.F
043
*** EMPTY ***
.F
044
DO NOT SET N2LAST EQUAL TO N1.
(IF NRH <= NCH AND NO SINGULAR VALUES ARE TRUNCATED, ALL OUTPUT EMACS WILL BE 100%.)
.F
045
DO NOT SET N3LAST EQUAL TO N1.
(IF NCH <= NRH AND NO SINGULAR VALUES ARE TRUNCATED, ALL INPUT EMACS WILL BE 100%.)
.F
046
INVALID ENTRY IN ARRAY PAR().  PAR(1), PAR(2), AND PAR(3) MUST BE NONZERO.
.F
047
NSFRST CANNOT BE <= 0.
.F
048
MXORDR MUST BE A POSITIVE INTEGER, NO LARGER THAN IORDR0=MIN(NRH,NCH)
.F
049
TWO INPUT (REFERENCE) COORDINATE CODES ARE THE SAME.
.F
050
IOPT.NE.0;  NON-NEGATIVE VALUES MUST BE ENTERED FOR BOTH PAR(1) AND PAR(2).
.F
051
IOPT=3.  A NON-NEGATIVE VALUE MUST BE ENTERED FOR PAR(4).
.F
```

```
052
A REQUESTED TAPE1 DATA FILE COULD NOT BE OPENED.  SEE MESSAGE ABOVE.  CHECK CORRECT SPELLING IN USER INPUT FILE.
ALSO CHECK TO BE SURE THAT 'T1' WAS NOT INCLUDED IN THE NAME SPECIFIED IN THE USER INPUT FILE; E.G. TO ASSIGN
A TAPE1 FILE NAMED 'T1EXAMPLE' AS THE DATA FOR INPUT NO. 1, ENTER '$ INPUT1:=EXAMPLE' IN THE USER INPUT FILE.
.F
053
A REQUESTED COORDINATE-CODE FILE COULD NOT BE OPENED.  SEE MESSAGE ABOVE.  IF YOU DO NOT WISH TO USE COORDINATE-CODE FILE(S),
YOU MUST SPECIFY A NON-ZERO VALUE FOR USER PARAMETER 'MIDOPT' IN THE USER INPUT FILE.  FOR EXAMPLE, IF MIDOPT=1 THE PROGRAM
ASSIGNS RESPONSE COORDINATES 1X+, 2X+, 3X+, ETC. AS THE IDENTIFICATION CODES FOR EACH SUCCESSIVE DATA RECORD IN THE TAPE1 FILE(S).
.F
054
ERROR ENCOUNTERED READING A TAPE1 DATA FILE.  TRIED TO READ IN MTIM DATA SAMPLES.  AN END-OF-RECORD WAS ENCOUNTERED IF THERE
ARE FEWER THAN MTIM SAMPLES IN EACH RECORD.  SEE MESSAGE ABOVE FOR MORE SPECIFICS.
.F
055
LESS THAN 1 CYCLE OF LOWEST-FREQ. MODE WILL BE USED WITH THE SELECTED ANALYSIS PARAMETERS.  MODIFY ANALYSIS PARAMETERS, OR
RERUN WITH NOFATL(55)=1 TO BYPASS THIS FATAL ERROR.  (SEE SPECIFIC VALUES LISTED ABOVE.)
.F
056
IOPT=2 (LOOP ON NSKIP), NIC > 1, AND IREFTU = 0.  UNDER THESE CONDITIONS, THE "REFERENCE COORDINATE" (FOR AMPLITUDE AND PHASE
DATA WRITTEN TO TAPE85) CAN VARY FROM ONE CASE TO THE NEXT.  THIS WILL MAKE AMPLITUDE AND PHASE DATA INCONSISTENT IF PLOTTED
VS. CASE NUMBER WITH ERAG15.  RE-RUN USING A VALUE FOR IREFTU = 1 THRU NIC, OR BY-PASS THIS FATAL ERROR BY ENTERING NOFATL(56)=1.
.F
057
NCH IS LESS THAN OR EQUAL TO NIC.  MAKE NCH LARGER OR NIC SMALLER.
.F
058
NRH IS LESS THAN OR EQUAL TO NST.  MAKE NRH LARGER OR NST SMALLER.
.F
059
PARAMETER MODELD CAN ONLY HAVE VALUES 0, 1, OR 2.
.F
060
ERROR READING COORDINATE-CODE FILE
.F
061
PARAMETER BIGPOS = 0.0.  COMMON /ERASYS/ PARAMETERS PROBABLY HAVE NOT BEEN
INITIALIZED PROPERLY (IN ERASYS.FOR).
.F
062
ITAPE(50) .NE. 0 OR 1.  YOU HAVE PROBABLY MISTYPED USER PARAMETER 'ITAPES'
AS 'ITAPE'.
.F
063
YOU CANNOT SPECIFY NSKIP > 0 WHEN MODELC > 0 OR MODELD > 0.
.F
064
MODELD AND MODELC CANNOT BE NON-ZERO SIMULTANEOUSLY.
.F
065
PARAMETER MODELC CAN ONLY HAVE VALUES 0, 1, OR 2.
.F
066
BOTH FR1FIR & FR2FIR MUST BE GIVEN TO APPLY FIR FILTERING.
.F
067
FR2FIR MUST BE > FR1FIR.
.F
068
BOTH FR1FIR & FR2FIR MUST BE NONNEGATIVE NOS. LESS THAN SF/2.
.F
069
REQUESTED IORFIR (ORDER OF FIR FILTER) > MAXMF = 1000.
.F
070
NOT ENOUGH DATA IS AVAILABLE TO FILTER DATA USING THE SELECTED VALUE OF IORFIR.
THERE MUST BE AT LEAST NTIM + IORFIR DATA PTS. AVAILABLE IN EACH TAPE1 RECORD.

SEE MESSAGE ABOVE FOR DETAILS.
.F
071
ILLEGAL VALUE IN NSTOWT().  ALL VALUES MUST BE BETWEEN 1 AND MST.
.F
072
ILLEGAL VALUE IN NITOWT().  ALL VALUES MUST BE BETWEEN 1 AND MIC.
F
073
ILLEGAL VALUE OF MXDNTM. MXDNTM MUST BE >0 AND <= MTIM.
.W
001
N1 DOES NOT EQUAL 1.  EIGENVALUES HAVE ALIASED UNLESS THE DATA BANDWIDTH WAS LESS THAN (SF/2)/N1.
.W
002
NRH IS NOT GREATER THAN NST.  COMPLEX EIGENVALUES WITH NEARLY MONOPHASE EIGENVECTORS MAY NOT BE IDENTIFIED WELL.
.W
003
***
.W
004
YOU HAVE SELECTED N2>N1 OR N2 IS NOT A FACTOR OF N1.  BETTER TO SELECT N2 AS A FACTOR OF N1 IF POSSIBLE.
.W
005
```

```
YOU HAVE SELECTED N3>N1 OR N3 IS NOT A FACTOR OF N1.  BETTER TO SELECT N3 AS A FACTOR OF N1 IF POSSIBLE.
.W
006
NO S.V. TRUNCATION: OMAC PROVIDES NO INFORMATION (ALWAYS 100%)
.W
007
NO S.V. TRUNCATION: IMAC PROVIDES NO INFORMATION (ALWAYS 100%)
.W
008
NO MODES WERE WRITTEN TO TAPE88 BECAUSE NONE SATISFIED T88MAC CUTOFF CRITERION.  (DEFAULT T88MAC = 80%).
.W
009
CUMULATIVE % OF VARIANCE AT SINGULAR-VALUE CUTOFF POINT IS LESS THAN 99.9%.  THIS IS TOO LOW FOR MOST
SITUATIONS. MORE SINGULAR VALUES SHOULD PROBABLY BE RETAINED.
.W
010
YOU HAVE SET THE SINGULAR VALUE TRUNCATION HIGHER THAN THAT CORRESPONDING TO RNKTL0, THE DEFAULT RANK TOLERANCE
DETERMINED BY MACHINE PRECISION.  A LOWER ORDER SHOULD PROBABLY BE USED.
.W
011
A RATIO BETWEEN CONSECUTIVE SINGULAR VALUES >= 20 WAS DETECTED. MXFLAG WAS CHANGED TO 1 AND ALL OTHER S.V. CUTOFF
CRITERIA WERE DISABLED.
.W
012
YOU HAVE SELECTED NRH [MRH] SUCH THAT THE LAST BLOCK ROW IN THE DATA MATRICES IS ONLY PARTIALLY FULL; I.E., THE NO.
OF ROWS IN THE LAST BLOCK IS LESS THAN 'NSTBOT'.  IT IS PREFERABLE TO HAVE THE LAST BLOCK FULL, SINCE EMAC CAN ONLY
BE COMPUTED FOR THOSE MEASUREMENTS WHICH APPEAR IN THIS BLOCK.  SEE RECOMMENDATION BELOW.
.W
013
YOU HAVE SELECTED NCH [MCH] SUCH THAT THE LAST BLOCK COL IN THE DATA MATRICES IS ONLY PARTIALLY FULL; I.E., THE NO.
OF COLS IN THE LAST BLOCK IS LESS THAN 'NIC'.  IT IS PREFERABLE TO HAVE THE LAST BLOCK FULL, SINCE EMAC CAN ONLY BE
COMPUTED FOR THOSE INITIAL CONDITIONS WHICH APPEAR IN THIS BLOCK.  SEE RECOMMENDATION BELOW.
.W
014
BECAUSE IREFTU=0 AND NIC>1, THE AMPLITUDE & PHASE RESULTS WRITTEN TO TAPE85 CAN CORRESPOND
TO DIFFERENT REFERENCE COORDINATES VS. CASE NO., WHICH MAY CAUSE MISINTERPRETATION
WHEN PLOTTED USING ERAG15.  SPECIFY A NON-ZERO VALUE FOR IREFTU TO INSURE COMPARABLE AMPLITUDE AND
PHASE RESULTS VS. CASE NO.
.W
015
LESS THAN 2 CYCLES OF LOWEST-FREQ. MODE IS BEING USED IN THIS ANALYSIS.  AT LEAST 2 CYCLES SHOULD BE USED IN MOST
SITUATIONS.
```

APPENDIX D - PRETEST PLANNING: MODAL RESPONSE AMPLITUDES VS. NOISE FLOOR

This appendix describes a procedure for calculating individual modal response amplitudes based on a NASTRAN model and comparing them with an estimated measurement noise floor. These calculations assist the development of adequate excitation for identification purposes. The Mini-Mast IRF data from Chapter 3 are used as an example. Modal responses amplitudes in the 20-50 Hz frequency range due to unit impulse excitation (modal IRFs) are calculated and plotted. There are 13 modes in this frequency interval.

Program ERAP10B computes modal response amplitudes (either individually or in combination) using a discrete-time state space model (A,B,C,D).[239] The modal responses are written out in ERA Tape1 format. Program ERAP9 generates the state space model for ERAP10B using frequency and mode shape data obtained from the Mini-Mast NASTRAN mode shape file (ERA$MMST_NAS:MMST_NASEIGV_900110_TESTDOFS.UNV). The state space model is saved in Tape79 (MATRIXx) format. Program ERAP92 calculates root-mean-square (rms) amplitudes of each modal response using all 312 responses (104 responses x 3 shakers) over a specified time interval. Program ERAG92 then plots these rms results on a mode-by-mode basis as a function of frequency. Noise floor information requested by program ERAG92 is obtained in this example from the output listing of program ERAP99 which is run in Section 3.2.

In summary, the following 4 programs are run in sequence to create a plot of IRF modal response amplitudes for the Mini-Mast demonstration problem:

1. **ERAP9** - Generates a discrete-time (A,B,C,D) model in Tape79 format containing all modes from 20 to 50 Hz. The modal parameters are read from the NASTRAN .UNV file. A sampling frequency of 500 Hz (10 times the upper frequency of interest) is selected to provide a close approximation of the dynamic response of a continuous-time model.

2. **ERAP10B** - Calculates individual modal impulse responses using the discrete-time (A,B,C,D) model generated by ERAP9. Responses are saved in Tape1 format.

3. **ERAP92** - Calculates rms values of the individual modal impulse responses over a specified time window.

[239]Program ERAP10B calculates the dynamic response of an ERA-identified state space model from results stored on Tape79 in MATRIXx format. The dynamic response of a NASTRAN model can be obtained by first creating a pseudo Tape79 file using program ERAP9.

4. **ERAG92** - Plots the results of ERAP92 vs. frequency with the measurement noise floor shown as a dashed line. The noise floor level is obtained from ERAP99 output generated in Section 3.2 (GO Input files P99_SH1_DEMO, P99_SH2_DEMO, and P99_SH3_DEMO).

These steps generate the plot shown in **Fig. D-1**.

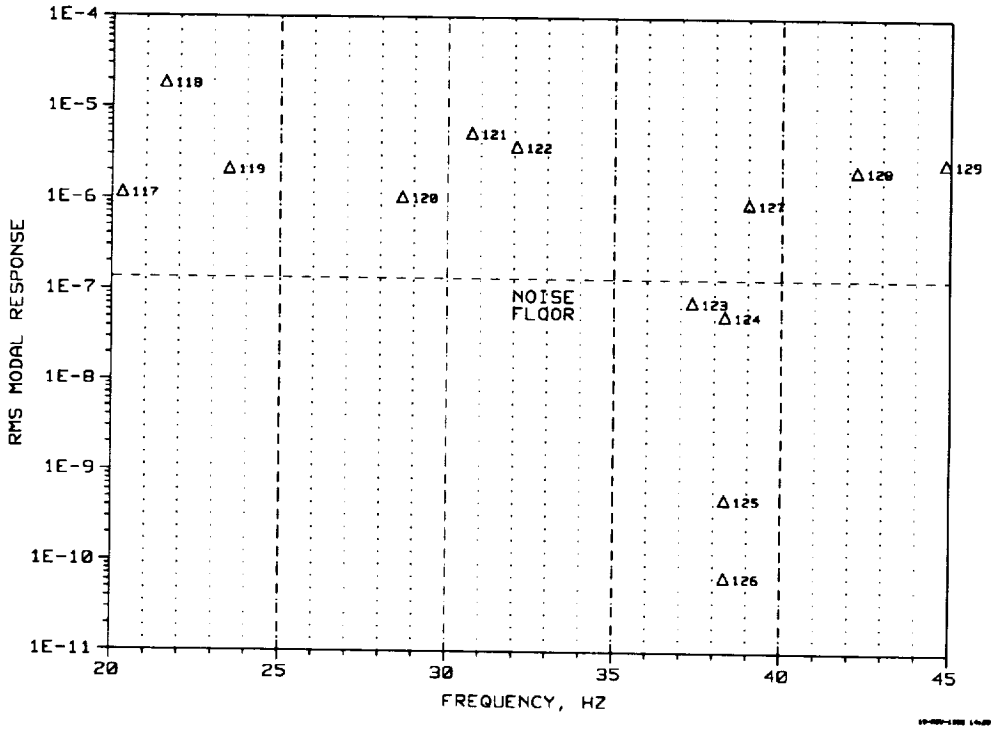


Fig. D-1. Individual Modal Response Amplitudes vs. Noise Floor for Demonstration Problem of Chapter 3, 20-50 Hz [G92_DEMO]

The remainder of this appendix describes the various GO Input files used to generate Fig. D-1.

The results shown in Fig. D-1 explain why only 2 modes, both of low confidence, are identified by ERA in the frequency range of 37 to 39 Hz (see Fig. 3-14). Note that the noise floor indicated in Fig. D-1 (1.35E-7) is the overall rms noise floor. In the ERA analysis discussed in Chapter 3, bandlimited data are analyzed, so that the filtered rms noise floor is somewhat lower than that shown (rms noise floor in 20-50 Hz bandwidth is 8.25E-8).

Here is a listing of file P9_20_50_DEMO.COM:

```
$! P9_20_50_DEMO.COM
```

```
$!
$ RUN ERA$EXES:ERAP9
ERA$MMST_NAS:MMST_NASEIGV_900110_TESTDOFS.UNV  NASTRAN MODE SHAPE .UNV FILE
79NASTRAN_20_50_500HZ.DAT   EQUIVALENT TAPE79 OUTPUT FILE
500     SAMPLING FREQ. (HZ)  FOR DISCRETE STATE-SPACE MODEL
3       NIC
100201,3  INPUT 1, LOCATION & DIRECTION
167,2           2
100203,3        3
104     NST
40,1    OUTPUT 1, LOCATION & DIRECTION
41,1           2
42,1           3
58,1           4
59,1           5
60,1           6
76,1           7
77,1           8
78,1           9
94,1          10
95,1          11
96,1          12
112,1         13
113,1         14
114,1         15
130,1         16
131,1         17
132,1         18
148,1         19
149,1         20
150,1         21
166,1         22
167,1         23
168,1         24
184,1         25
185,1         26
186,1         27
202,1         28
203,1         29
204,1         30
220,1         31
221,1         32
222,1         33
238,1         34
239,1         35
240,1         36
256,1         37
257,1         38
258,1         39
274,1         40
275,1         41
276,1         42
292,1         43
293,1         44
```

294,1	45
310,1	46
311,1	47
312,1	48
328,1	49
329,1	50
330,1	51
40,2	52
41,2	53
42,2	54
58,2	55
59,2	56
60,2	57
76,2	58
77,2	59
78,2	60
94,2	61
95,2	62
96,2	63
112,2	64
113,2	65
114,2	66
130,2	67
131,2	68
132,2	69
148,2	70
149,2	71
150,2	72
166,2	73
167,2	74
168,2	75
184,2	76
185,2	77
186,2	78
202,2	79
203,2	80
204,2	81
220,2	82
221,2	83
222,2	84
238,2	85
239,2	86
240,2	87
256,2	88
257,2	89
258,2	90
274,2	91
275,2	92
276,2	93
292,2	94
293,2	95
294,2	96
310,2	97
311,2	98

```
312,2         99
328,2        100
329,2        101
330,2        102
100201,3     103
100203,3     104
117       FIRST MODE FROM NASTRAN .UNV FILE TO INCLUDE
129       LAST  MODE FROM NASTRAN .UNV FILE TO INCLUDE
1         1=SAME ZETA FOR ALL MODES, 2=SPECIFY ZETA BY RANGES OF MODES
1.0       DAMPING FACTOR (ZETA) IN %
1         TYPE OF RESPONSE SENSOR. 1=DISP,2=VEL,3=ACCEL
```

The following information is printed on your computer screen when P9_20_50_DEMO.COM is run:

```
ERAP9. BUILD EQUIVALENT TAPE79 FILE (DISCRETE A,B,C,D MODEL) FOR ERAP10B FROM
NASTRAN MODE SHAPE (TYPE 55) .UNV FILE

NASTRAN MODE SHAPE .UNV INPUT FILE? [DEFAULT FILE TYPE = .UNV]
ERA$MMST_NAS:MMST_NASEIGV_900110_TESTDOFS.UNV


TAPE79 OUTPUT FILE?  [DEFAULT FILE TYPE = .DAT]
79NASTRAN_20_50_500HZ.DAT


SAMPLING FREQUENCY (HZ) FOR DISCRETE MODEL? (10.0)
  500.0000

NIC ?  (1)
          3

ENTER THE   3 INPUT LOCATION NOS. & DIRECTIONS (+/- 1,2,3):
    1:      100201   3
    2:         167   2
    3:      100203   3

NST ?  (1)
        104

ENTER THE 104 OUTPUT LOCATION NOS. & DIRECTIONS (+/- 1,2,3):
    1:          40   1
    2:          41   1
    3:          42   1
    4:          58   1
    5:          59   1
    6:          60   1
    7:          76   1
    8:          77   1
    9:          78   1
   10:          94   1
   11:          95   1
   12:          96   1
```

```
13:      112   1
14:      113   1
15:      114   1
16:      130   1
17:      131   1
18:      132   1
19:      148   1
20:      149   1
21:      150   1
22:      166   1
23:      167   1
24:      168   1
25:      184   1
26:      185   1
27:      186   1
28:      202   1
29:      203   1
30:      204   1
31:      220   1
32:      221   1
33:      222   1
34:      238   1
35:      239   1
36:      240   1
37:      256   1
38:      257   1
39:      258   1
40:      274   1
41:      275   1
42:      276   1
43:      292   1
44:      293   1
45:      294   1
46:      310   1
47:      311   1
48:      312   1
49:      328   1
50:      329   1
51:      330   1
52:       40   2
53:       41   2
54:       42   2
55:       58   2
56:       59   2
57:       60   2
58:       76   2
59:       77   2
60:       78   2
61:       94   2
62:       95   2
63:       96   2
64:      112   2
65:      113   2
66:      114   2
```

```
  67:        130   2
  68:        131   2
  69:        132   2
  70:        148   2
  71:        149   2
  72:        150   2
  73:        166   2
  74:        167   2
  75:        168   2
  76:        184   2
  77:        185   2
  78:        186   2
  79:        202   2
  80:        203   2
  81:        204   2
  82:        220   2
  83:        221   2
  84:        222   2
  85:        238   2
  86:        239   2
  87:        240   2
  88:        256   2
  89:        257   2
  90:        258   2
  91:        274   2
  92:        275   2
  93:        276   2
  94:        292   2
  95:        293   2
  96:        294   2
  97:        310   2
  98:        311   2
  99:        312   2
 100:        328   2
 101:        329   2
 102:        330   2
 103:     100201   3
 104:     100203   3

FIRST MODE FROM .UNV FILE TO INCLUDE ?  (1)
       117

LAST MODE FROM .UNV FILE TO INCLUDE ? [LARGE NO. FOR ALL]  (1000)
       129

METHOD FOR SPECIFYING MODAL DAMPING ?  (1)
 1. SAME VALUE FOR ALL MODES
 2. VARIOUS VALUES FOR VARIOUS RANGES OF MODES
         1

DAMPING FACTOR (%) FOR ALL MODES ?  (1.0)
  1.000000

TYPE OF RESPONSE SENSORS ?  (3)
```

```
1. DISPLACEMENT
2. VELOCITY
3. ACCELERATION
          1
READ MODE NO.  117.  FREQ. =    20.308
READ MODE NO.  118.  FREQ. =    21.570
READ MODE NO.  119.  FREQ. =    23.474
READ MODE NO.  120.  FREQ. =    28.648
READ MODE NO.  121.  FREQ. =    30.721
READ MODE NO.  122.  FREQ. =    32.064
READ MODE NO.  123.  FREQ. =    37.335
READ MODE NO.  124.  FREQ. =    38.309
READ MODE NO.  125.  FREQ. =    38.322
READ MODE NO.  126.  FREQ. =    38.322
READ MODE NO.  127.  FREQ. =    39.012
READ MODE NO.  128.  FREQ. =    42.222
READ MODE NO.  129.  FREQ. =    44.856

OUTPUT (DISCRETE A,B,C,D MODEL) WRITTEN TO FILE:
79NASTRAN_20_50_500HZ.DAT
```

Here is a listing of file P10B_1_DEMO.COM:

```
$! P10B_1_DEMO.COM
$!
$ RUN ERA$EXES:ERAP10B
79NASTRAN_20_50_500HZ     TAPE79 FILE
3  1=COMPUTE PRF, 2=EXCITATION HISTORIES PROVIDED,3=COMPUTE IRFS
T1_MODAL_IRFS_1        OUTPUT FILE TO RECEIVE COMPUTED RESPONSES (TAPE1 FORMAT)
1      CHANGE ALL NEGATIVE (UNSTABLE) DAMPING VALUES TO 0.0? 1=YES
0      COMPARE CALCULATE RESPONSES WITH MEASURED RESPONSES (RMS) ?  1=YES
1      FIRST CASE TO USE
1      LAST CASE TO USE
1      STEP CASE TO USE
420    NO. OF TIME PTS. TO CALCULATE
1      FIRST EXCIT. (INPUT) TO USE
1      LAST  EXCIT. (INPUT) TO USE
1      FIRST RESPONSE NO. (OUTPUT) TO USE
104    LAST  RESPONSE NO. (OUTPUT) TO USE
1      PRINT OUT MODAL FREQS, ZETAPS, ETC? 1=YES
1      FIRST MODE TO INCLUDE IN CALCULATION
13     LAST  MODE TO INCLUDE IN CALCULATION
2      INCLUDE THESE MODES SIMULTANEOUSLY(1) OR INDIVIDUALLY(2) ?
1      OUTPUT DATA PARSING FACTOR. 1=WRITE EVERY DATA PT, 2=WRITE EVERY 2ND
```

GO Input files P10B_2_DEMO.COM and P10B_3_DEMO.COM for shakers 2 and 3 are similar in content.

The following information appears on your computer screen when P10B_1_DEMO.COM is run:

```
ERAP10B. SIMULATION OF DISCRETE-TIME LINEAR SYSTEMS WITH ARBITRARY
INPUTS.  USES [Z_EVALUES,BDMODAL,CDMODAL,DDMODAL] FROM TAPE79.
  SOLVES:   X(N+1) = AX(N) + BU(N)
              Y(N) = CX(N) + DU(N)
 *** ASSUMING BLOCK DIAGONAL A MATRIX ***

TAPE79 FILENAME ?  [DEFAULT FILE TYPE = .DAT]
79NASTRAN_20_50_500HZ.DAT

CHOOSE ONE:  (2)
 1. COMPUTE PULSE RESPONSE
 2. EXCITATION HISTORIES PROVIDED
 3. COMPUTE APPROX. IMPULSE RESPONSE (NORMALIZED PULSE RESPONSE)
          3

TAPE1 FILENAME FOR WRITING OUTPUT DATA ? [DEFAULT TYPE = .DAT]
T1_MODAL_IRFS_1.DAT

CHANGE ALL NEGATIVE (UNSTABLE) DAMPING VALUES TO 0.0? 1=YES (1)
          1

WOULD YOU LIKE TO CALCULATE THE AVG. % ERROR
BETWEEN THE CALCULATED RESPONSES AND A SET OF MEASURED
RESPONSES ? 1=YES  (0)
          0

LOOPOP ........................... 0
PAR(1) - PAR(5) .................. -999.0 -999.0 -999.0 -999.0 -999.0
NCASES ...........................    1

FIRST CASE TO USE ?  (1)
          1

LAST CASE TO USE ?  (   1)
          1

STEP CASE TO USE [I.E., DO LOOP INCREMENT] ?  (1)
          1

CASE NO. ..............................    1
 NO. OF INIT. CONDITIONS (INPUTS) ....   3
 NO. OF MEASUREMENTS (OUTPUTS) ....... 104
 IORDER ..............................  26
 DT ..................................  0.0020
 NO. OF REAL EIGENVALUES .............   0
 NO. OF PAIRS OF COMPLEX EIGENVALUES .  13


NO. OF TIME POINTS TO CALCULATE ?  ( 1000)
        420

FIRST INITIAL CONDITION NO. [INPUT NO.] TO INCLUDE IN CALCULATION ?  (1)
          1
```

```
LAST INITIAL CONDITION NO. [INPUT NO.] TO INCLUDE IN CALCULATION ?  ( 3)
          1

FIRST RESPONSE NO. [OUTPUT NO.] TO CONSTRUCT ?  (1)
          1

LAST RESPONSE NO. [OUTPUT NO.] TO CONSTRUCT ?  (104)
        104

PRINT OUT MODAL FREQS, ZETAPS, ETC.? 1=YES  (1)
          1
VARIABLE z_evalues READ FROM TAPE79.
VARIABLE cd_modal READ FROM TAPE79.
VARIABLE bd_modal READ FROM TAPE79.
VARIABLE dd_modal READ FROM TAPE79.
VARIABLE fd READ FROM TAPE79.
VARIABLE zetap READ FROM TAPE79.
VARIABLE zeta2p READ FROM TAPE79.
VARIABLE cmi READ FROM TAPE79.
VARIABLE msr READ FROM TAPE79.

NO. OF REAL EIGENVALUES =      0
NO. OF MODES (PAIRS OF COMPLEX EIGENVALUES) =     13 :

FIRST MODE TO INCLUDE IN THE CALCULATION ? (1)
          1

LAST MODE TO INCLUDE IN THE CALCULATION ? [ENTER LARGE NO. FOR ALL]  (  13)
         13

HOW SHOULD RESPONSE BE COMPUTED ? (1)
 1. USING ALL MODES SIMULTANEOUSLY
 2. USING EACH MODE INDIVIDUALLY
          2

OUTPUT DATA PARSING FACTOR ?  (1)
 1 = WRITE OUT EVERY CALCULATED DATA PT.
 2 = WRITE OUT EVERY 2ND CALCULATED DATA PT.
 ETC.
          1

 MODE        FD       ZETAP     ZETA2P      CMI      MSR
  ---        --       -----     ------      ---      ---
    1    20.307      1.000      1.000   100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400

FOR CASE NO.    1:
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
NTIM =   420
(OUTPUT DATA PARSING FACTOR =      1)
```

```
 MODE        FD       ZETAP     ZETA2P       CMI      MSR
  ---        --       -----     ------       ---      ---
    2    21.569       1.000      1.000    100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400

FOR CASE NO.    1:
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
NTIM =   420
(OUTPUT DATA PARSING FACTOR =      1)

 MODE        FD       ZETAP     ZETA2P       CMI      MSR
  ---        --       -----     ------       ---      ---
    3    23.473       1.000      1.000    100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400

FOR CASE NO.    1:
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
NTIM =   420
(OUTPUT DATA PARSING FACTOR =      1)

 MODE        FD       ZETAP     ZETA2P       CMI      MSR
  ---        --       -----     ------       ---      ---
    4    28.647       1.000      1.000    100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400

FOR CASE NO.    1:
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
NTIM =   420
(OUTPUT DATA PARSING FACTOR =      1)

 MODE        FD       ZETAP     ZETA2P       CMI      MSR
  ---        --       -----     ------       ---      ---
    5    30.719       1.000      1.000    100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400

FOR CASE NO.    1:
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
```

```
NTIM =   420
(OUTPUT DATA PARSING FACTOR =      1)

 MODE        FD       ZETAP     ZETA2P      CMI      MSR
  ---        --       -----     ------      ---      ---
    6    32.062       1.000      1.000   100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400

FOR CASE NO.    1:
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
NTIM =   420
(OUTPUT DATA PARSING FACTOR =      1)

 MODE        FD       ZETAP     ZETA2P      CMI      MSR
  ---        --       -----     ------      ---      ---
    7    37.333       1.000      1.000   100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400

FOR CASE NO.    1:
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
NTIM =   420
(OUTPUT DATA PARSING FACTOR =      1)

 MODE        FD       ZETAP     ZETA2P      CMI      MSR
  ---        --       -----     ------      ---      ---
    8    38.307       1.000      1.000   100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400

FOR CASE NO.    1:
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
NTIM =   420
(OUTPUT DATA PARSING FACTOR =      1)

 MODE        FD       ZETAP     ZETA2P      CMI      MSR
  ---        --       -----     ------      ---      ---
    9    38.320       1.000      1.000   100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400

FOR CASE NO.    1:
```

```
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
NTIM =   420
(OUTPUT DATA PARSING FACTOR =      1)

 MODE        FD       ZETAP     ZETA2P      CMI      MSR
  ---        --       -----     ------      ---      ---
   10    38.320       1.000      1.000   100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400

FOR CASE NO.    1:
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
NTIM =   420
(OUTPUT DATA PARSING FACTOR =      1)

 MODE        FD       ZETAP     ZETA2P      CMI      MSR
  ---        --       -----     ------      ---      ---
   11    39.010       1.000      1.000   100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400

FOR CASE NO.    1:
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
NTIM =   420
(OUTPUT DATA PARSING FACTOR =      1)

 MODE        FD       ZETAP     ZETA2P      CMI      MSR
  ---        --       -----     ------      ---      ---
   12    42.220       1.000      1.000   100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400

FOR CASE NO.    1:
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
NTIM =   420

 MODE        FD       ZETAP     ZETA2P      CMI      MSR
  ---        --       -----     ------      ---      ---
   13    44.854       1.000      1.000   100.00   100.00
NT =   100
NT =   200
NT =   300
NT =   400
```

```
FOR CASE NO.    1:
WROTE OUT  104 RECORDS OF CALCULATED RESPONSE DATA TO FILE
T1_MODAL_IRFS_1.DAT
NTIM =    420
(OUTPUT DATA PARSING FACTOR =      1)
```

After all 3 P10B GO Input files have been executed, the following new Tape1 files will exist. Each Tape1 file contains 1352 records (104 responses x 13 modes) of 420 data points each.

```
DIR/SIZE T1_MODAL*

Directory SDBRP$DKA0:[PAPPA.DEMO]

T1_MODAL_IRFS_1.DAT;1
                          4447  19-NOV-1993 15:19:44.78  [SDB,PAPPA]
T1_MODAL_IRFS_2.DAT;1
                          4447   5-NOV-1993 15:22:15.13  [SDB,PAPPA]
T1_MODAL_IRFS_3.DAT;1
                          4447   5-NOV-1993 15:24:16.65  [SDB,PAPPA]

Total of 3 files, 13341 blocks.
```

These are large data files. They can be deleted after the results shown at the end of this Appendix (Fig. D-1) are obtained.

Here is a listing of file P92_DEMO.COM:

```
$! P92_DEMO.COM
$!
$ RUN ERA$EXES:ERAP92
T1_MODAL_IRFS_1.DAT  TAPE1 FILENAME
P92_DEMO.OUT  OUTPUT FILENAME W/ RMS & PEAK RESULTS
0     NSKIP
420   NTIM
104   NO. OF CONSECUTIVE RECORDS TO GROUP TOGETHER
13    NO. OF GROUPS (MODES) TO PROCESS
117   MODE NO. CORRESPONDING TO GROUP NO. 1
2     NO. OF ADDITIONAL TAPE1 FILES TO READ SIMULTANEOUSLY
T1_MODAL_IRFS_2.DAT   TAPE1 # 2 FILENAME
T1_MODAL_IRFS_3.DAT   TAPE1 # 3 FILENAME
```

The following information appears on your computer screen when P92_DEMO is run:

```
ERAP92.  CALCULATE RMS & PEAK VALUES OF TAPE1 DATA
OVER A SPECIFIED TIME WINDOW AND ACROSS
MULTIPLE RECORDS. ALSO, MORE THAN 1 TAPE1 FILE CAN
BE READ SIMULTANEOUSLY.

ENTER INPUT TAPE1 FILE NAME  [DEFAULT FILE TYPE = .DAT]
```

```
T1_MODAL_IRFS_1.DAT

ENTER OUTPUT TAPE1 FILE NAME FOR RMS & PEAK RESULTS [DEFAULT FILE TYPE = .DAT]
P92_DEMO.OUT

NSKIP ?  (0)
          0

NTIM ?  (  420)
         420

NO. OF CONSECUTIVE RECORDS TO GROUP TOGETHER ?  (1)
         104

NO. OF GROUPS OF DATA (MODES) TO PROCESS ?  (1)
          13

MODE NO. CORRESPONDING TO GROUP NO. 1 ?  (1)
         117

NO. OF ADDITIONAL TAPE1 FILES TO READ SIMULTANEOUSLY ?  (0)
           2

ENTER TAPE1 FILE NAME NO.    2
T1_MODAL_IRFS_2.DAT

ENTER TAPE1 FILE NAME NO.    3
T1_MODAL_IRFS_3.DAT
```

GROUP	MODE	RMS	PEAK DYNAMIC
1	117	1.09823E-06	7.68491E-06
2	118	1.76724E-05	9.65404E-05
3	119	2.00385E-06	1.54558E-05
4	120	1.00394E-06	9.89019E-06
5	121	5.06295E-06	3.62371E-05
6	122	3.61100E-06	2.92101E-05
7	123	7.35555E-08	8.42052E-07
8	124	5.23499E-08	4.41164E-07
9	125	4.77737E-10	3.73734E-09
10	126	6.56429E-11	6.45252E-10
11	127	8.80674E-07	6.41487E-06
12	128	2.05572E-06	1.98677E-05
13	129	2.50735E-06	2.65547E-05

```
THESE RESULTS ALSO WRITTEN TO FILE:
P92_DEMO.OUT
```

Here is a listing of file G92_DEMO.COM:

```
$! G92_DEMO.COM
$!
$ RUN ERA$EXES:ERAG92
```

```
P92_DEMO.OUT  FILE CONTAINING RMS AND PEAK RESULTS
FREQS_AND_DAMPS.DAT  FILE WITH LIST OF FREQS.
1         PLOT TYPE: 1=RMS VS. FREQ, 2=PEAK VS. FREQ
1.35E-7   NOISE FLOOR
32        START X VALUE IN HZ FOR "NOISE FLOOR" LABEL ON PLOT
1         FONT TYPE
0.3       CHARACTER SIZE
100       SYMBOL SIZE AS % OF CHARACTER SIZE
1         WRITE MODE NUMBERS ADJACENT TO SYMBOLS? 1=YES
1         DELTA FOR X-AXIS MINOR TIC MARKS
0         FREQ. OF FIRST X-AXIS MINOR TIC MARK. 0=ORIGIN OF PLOT
1         INCLUDE VERTICAL DASHED LINES AT X-AXIS MAJOR TICS? 1=YES
1         ALSO PLOT DOTTED VERTICAL LINES AT MINOR TICS? 1=YES
0         MODIFY DEFAULT AXIS LABELS? 1=YES
```

The following information is printed on your computer screen when G92_DEMO.COM is run:

```
ERAG92.  PLOT MODAL STRENGTHS (RMS OR PEAK)
COMPUTED USING ERAP10B & ERAP92 VS. FREQUENCY

FILE NAME CONTAINING RMS AND PEAK RESULTS ?
(OUTPUT OF ERAP92)  [DEFAULT TYPE = .DAT]
P92_DEMO.OUT


FILE NAME CONTAINING LIST OF MODAL FREQUENCIES ? [DEFAULT TYPE = .DAT
FREQS_AND_DAMPS.DAT


PLOT TYPE ?  (1)
 1. RMS  MODAL RESPONSE VS. FREQUENCY
 2. PEAK MODAL RESPONSE VS. FREQUENCY
          1

NOISE FLOOR ?  0.0=NONE (0.0)
 1.3499999E-07

START X VALUE IN HZ FOR 'NOISE FLOOR' LABEL ON PLOT ?  (10.0)
  32.00000

FONT TYPE ?  (1)
 1 = STICK FONT
 2 = LETTER QUALITY - BOLD
 3 = LETTER QUALITY - STD.
          1

CHARACTER SIZE IN CM.?  (0.3)
 0.3000000

SYMBOL SIZE AS % OF CHARACTER SIZE?  (80.0)
  100.0000
```

```
WRITE MODE NUMBERS ADJACENT TO SYMBOLS ? 1=YES  (0)
          1

DELTA FOR X-AXIS MINOR TIC MARKS ? 0 = NONE  (1.0)
  1.000000

FREQ. OF FIRST X-AXIS MINOR TIC MARK ?  0.0 = ORIGIN OF PLOT. (0.0)
 0.0000000E+00

INCLUDE X-AXIS GRID LINES AT EACH MAJOR TIC) ?  1=YES  (1)
          1

ALSO ADD ADDITIONAL DOTTED VERTICAL LINES AT MINOR TIC MARKS ?  1=YES.  (1)
          1

MODIFY DEFAULT AXIS NUMBERS ?  1=YES  (0)
          0

NO. OF MODES READ IN:   13

GRAPHICS DEVICE NUMBER ?  (4)
  1 = TEK. 4010
  2 = TEK. 4014
  3 = TEK. 4025
  4 = TEK. 4107
  5 = TEK. 4115B
  6 = HP 2647/2648
  7 = DEC VT240
  8 = HPGL TALL
  9 = HPGL WIDE
 10 = POSTSCRIPT TALL
 11 = POSTSCRIPT WIDE
```

APPENDIX E - BIBLIOGRAPHY

Publications discussing ERA, modified forms of ERA, comparisons with ERA, applications, etc., in chronological order:

1984

Juang, J.-N. and Pappa, R. S., "An Eigensystem Realization Algorithm (ERA) for Modal Parameter Identification and Model Reduction," Proceedings of the NASA/JPL Workshop on Identification and Control of Flexible Space Structures, San Diego, CA, June 1984.

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Brumfield, M. L., Pappa, R. S., Miller, J. B., and Adams, R. R., "Orbital Dynamics of the OAST-1 Solar Array Using Video Measurements," AIAA Paper 85-0758, April 1985.

Juang, J.-N. and Pappa, R. S., "An Eigensystem Realization Algorithm for Modal Parameter Identification and Model Reduction," *Journal of Guidance, Control, and Dynamics*, Vol. 8, No. 5, September-October 1985, pp. 620-627.

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1986

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Pappa, R. S. and Juang, J.-N., "Studies of Modal-Identification Performance Using Hybrid Data," *The International Journal of Analytical and Experimental Modal Analysis*, Vol. 2, No. 2, April 1987, pp. 99-108.

Liang, Z. and Inman, D. J., "An Alternative Time Domain Method for Modal Analysis," Proceedings of the 5th International Modal Analysis Conference, London, England, April 1987, pp. 127-132.

Longman, R. W. and Juang, J.-N., "A Variance Based Confidence Criterion for ERA Identified Modal Parameters," Proceedings of the AAS/AIAA Astrodynamics Specialist Conference, Kalispell, Montana, August 1987.

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APPENDIX F - DIRECTORY OF ALL FILES

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WRITE_TK50_TAPE.COM;1
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Total of 126 files, 171 blocks.

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STRINGLIB.OLB;1            41  30-APR-1984 12:56:56.77  [PAPPA]
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TEST.FOR;1                  4  24-SEP-1984 17:58:07.76  [PAPPA]
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VAXFONTS.COM;1              2  26-OCT-1990 13:07:01.87  [PAPPA]
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VIEW3D.CMN;1                1   9-DEC-1986 10:34:40.84  [PAPPA]
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Total of 234 files, 3655 blocks.

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ERAG15.EXE;1              167  21-APR-1994 10:50:03.81  [PAPPA]
ERAG2.EXE;1               114  27-SEP-1993 08:30:47.40  [PAPPA]
ERAG25.EXE;1              137  27-SEP-1993 08:35:34.56  [PAPPA]
ERAG26.EXE;1              106  27-SEP-1993 08:35:56.92  [PAPPA]
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ERAG2C.EXE;1              124  27-SEP-1993 08:31:35.21  [PAPPA]
ERAG3.EXE;1               165   7-APR-1994 14:02:52.00  [PAPPA]
ERAG3B.EXE;1              150   7-APR-1994 14:05:28.57  [PAPPA]
ERAG4.EXE;1               128   1-NOV-1993 15:21:28.30  [PAPPA]
ERAG5.EXE;1               143  13-APR-1994 15:48:00.69  [PAPPA]
ERAG50.EXE;1              142   7-APR-1994 15:11:52.15  [PAPPA]
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ERAG6.EXE;1               107  27-SEP-1993 08:34:04.99  [PAPPA]
ERAG7.EXE;1               430   7-APR-1994 13:57:27.84  [PAPPA]
ERAG92.EXE;1              111  19-NOV-1993 15:52:37.30  [PAPPA]
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ERAP2D.EXE;1                15  17-SEP-1992 14:17:54.18  [PAPPA]
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Total of 78 files, 4406 blocks.

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P27.COM;1                     1   2-NOV-1992 13:45:27.16  [PAPPA]
P2B.COM;1                     2  30-MAR-1993 09:08:16.98  [PAPPA]
P2_DEMO.COM;1                 2  31-MAR-1994 10:40:58.75  [PAPPA]
P2_EOS_101X.COM;1             2  31-MAR-1994 10:57:01.23  [PAPPA]
P2_EOS_106Y.COM;1             2  31-MAR-1994 11:18:21.19  [PAPPA]
P2_EOS_2110Z.COM;1            2  31-MAR-1994 11:20:43.31  [PAPPA]
P3.COM;1                      1   5-MAR-1992 12:53:52.50  [PAPPA]
P30.COM;1                     4  30-APR-1992 10:06:41.87  [PAPPA]
P30_CEM1_DP1.COM;1            2  17-SEP-1992 13:16:11.20  [PAPPA]
P30_DP2_AF.COM;1              2  23-JUL-1992 15:30:08.92  [PAPPA]
P30_L1L.COM;1                 4  14-AUG-1992 16:23:57.01  [PAPPA]
P30_L1U.COM;1                 4  14-AUG-1992 16:50:39.97  [PAPPA]
P30_MMST_NAS_23Y_0_10_AF.COM;1
                              3   2-SEP-1992 10:47:40.43  [PAPPA]
P30_MMST_NAS_SH2_0_10_AF_DPS.COM;1
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                              3   2-SEP-1992 10:01:49.91  [PAPPA]
P30_MMST_SH2_0_10_AF.COM;1
                              4   2-SEP-1992 09:54:35.12  [PAPPA]
P30_ONEMODE.COM;1             2  19-AUG-1992 09:57:18.22  [PAPPA]
P3C.COM;1                     1   7-OCT-1991 17:07:15.01  [PAPPA]
P3_SH1_NST5.COM;1             1  31-MAR-1994 10:38:05.88  [PAPPA]
P4.COM;1                      1   7-APR-1994 08:52:41.99  [PAPPA]
P40.COM;1                     3  27-NOV-1991 14:57:32.95  [PAPPA]
P5.COM;1                      1   9-APR-1993 13:30:11.40  [PAPPA]
P5_201Z_203Z_DEMO.COM;1
                              1  14-OCT-1993 11:05:05.73  [PAPPA]
P5_203Z_201Z_DEMO.COM;1
                              1  14-OCT-1993 11:08:12.75  [PAPPA]
P5_SH2DP.COM;1                1  23-NOV-1993 14:33:38.23  [PAPPA]
P6.COM;1                      1  31-MAR-1993 09:42:22.45  [PAPPA]
P6_DEMO.COM;1                 1  10-JUL-1992 15:02:38.65  [PAPPA]
P76A_INIT_20_50.COM;1
                              1  21-SEP-1993 08:53:10.80  [PAPPA]
P76A_MIMO1.COM;1              1  17-SEP-1993 16:04:10.85  [PAPPA]
P76A_MIMO1_SH1.COM;1
                              1  17-SEP-1993 16:18:31.16  [PAPPA]
P76A_MIMO1_SH2.COM;1
                              1   7-JUL-1992 14:47:12.27  [PAPPA]
P76A_MIMO1_SH3.COM;1
                              1  17-SEP-1993 16:21:42.67  [PAPPA]
P76A_SISO1.COM;1              1   7-JUL-1992 14:48:20.02  [PAPPA]
P76A_SISO2.COM;1              1  17-SEP-1993 14:29:12.25  [PAPPA]
P76B.COM;1                    1  19-AUG-1992 08:34:42.55  [PAPPA]
P76C.COM;1                    1  14-MAY-1993 10:23:43.24  [PAPPA]
P76C_DF_IFFT.COM;1            1  25-JAN-1994 09:37:20.25  [PAPPA]
P76C_DF_LSIM.COM;1            1  25-JAN-1994 09:36:59.17  [PAPPA]
P76C_IRFS_AF_IFFT_1.COM;1
                              1   1-FEB-1994 10:50:42.36  [PAPPA]
P76C_IRFS_AF_IFFT_2.COM;1
                              1   1-FEB-1994 10:50:56.45  [PAPPA]
P76C_IRFS_AF_LSIM_1.COM;1
                              1   1-FEB-1994 10:51:10.03  [PAPPA]
P76C_IRFS_AF_LSIM_2.COM;1
                              1   1-FEB-1994 10:51:24.00  [PAPPA]
P76C_IRFS_DF_IFFT_1.COM;1
                              1   1-FEB-1994 10:51:37.30  [PAPPA]
P76C_IRFS_DF_IFFT_2.COM;1
                              1   1-FEB-1994 10:51:50.75  [PAPPA]
P76C_IRFS_DF_LSIM_1.COM;1
                              1   1-FEB-1994 10:52:04.52  [PAPPA]
P76C_IRFS_DF_LSIM_2.COM;1
                              1   1-FEB-1994 10:52:19.57  [PAPPA]
P76C_PRFS_AF_IFFT_1.COM;1
                              1   1-FEB-1994 10:59:33.66  [PAPPA]
P76C_PRFS_AF_IFFT_2.COM;1
                              1   1-FEB-1994 10:59:50.94  [PAPPA]
P76C_PRFS_AF_LSIM_1.COM;1
                              1   1-FEB-1994 10:59:11.34  [PAPPA]
P76C_PRFS_AF_LSIM_2.COM;1
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P76C_PRFS_AF_OKID_1.COM;1        1   1-FEB-1994 10:59:21.21  [PAPPA]
P76C_PRFS_AF_OKID_2.COM;1        1   8-FEB-1994 14:06:10.68  [PAPPA]
P76C_PRFS_DF_IFFT_1.COM;1        1   8-FEB-1994 14:06:41.31  [PAPPA]
P76C_PRFS_DF_IFFT_2.COM;1        1   1-FEB-1994 10:58:42.34  [PAPPA]
P76C_PRFS_DF_LSIM_1.COM;1        1   1-FEB-1994 10:58:53.75  [PAPPA]
P76C_PRFS_DF_LSIM_2.COM;1        1   1-FEB-1994 10:58:11.18  [PAPPA]
P76C_PRFS_DF_OKID_1.COM;1        1   1-FEB-1994 10:58:27.20  [PAPPA]
P76C_PRFS_DF_OKID_2.COM;1        1   8-FEB-1994 13:38:44.31  [PAPPA]
P79.COM;1                        1   8-FEB-1994 13:39:44.07  [PAPPA]
P79_DF_IRF_LSIM.COM;1            1  20-JUL-1993 10:56:43.81  [PAPPA]
P79_IRFS_DF_LSIM.COM;1           1  25-JAN-1994 10:50:03.44  [PAPPA]
P79_MIMO1.COM;1                  1  25-JAN-1994 14:56:54.64  [PAPPA]
P79_MIMO1_NONOISE.COM;1          1   2-JUL-1992 13:49:11.47  [PAPPA]
P79_MIMO2.COM;1                  1  21-JAN-1994 11:03:57.05  [PAPPA]
P79_SISO1.COM;1                  1   6-JUL-1992 15:28:03.59  [PAPPA]
P80.COM;1                        1   2-JUL-1992 13:50:21.91  [PAPPA]
P81_DEMO.COM;1                   1  26-OCT-1992 11:33:39.03  [PAPPA]
P81_MIMO1.COM;1                  1  22-SEP-1993 09:21:02.85  [PAPPA]
P82_DEMO.COM;1                   1  22-SEP-1993 15:59:16.53  [PAPPA]
P85.COM;1                        1  22-SEP-1993 12:52:24.84  [PAPPA]
P85B.COM;1                       1  27-JUL-1992 16:31:16.47  [PAPPA]
P88.COM;1                        1   8-JUL-1993 11:17:20.38  [PAPPA]
P88_1_DEMO.COM;1                 1  24-JUN-1993 16:04:45.10  [PAPPA]
P88_1_IRFS_DF_IFFT.COM;1         1  14-SEP-1993 08:57:55.56  [PAPPA]
P88_1_PRFS_DF_IFFT.COM;1         1  17-FEB-1994 13:17:54.59  [PAPPA]
P88_2_DEMO.COM;1                 2  17-FEB-1994 14:06:02.31  [PAPPA]
P88_2_IRFS_DF_IFFT.COM;1         1  14-SEP-1993 08:58:21.45  [PAPPA]
P88_2_PRFS_DF_IFFT.COM;1         1  17-FEB-1994 14:09:33.17  [PAPPA]
P88_DISCRETE_DEMO.COM;1          1  17-FEB-1994 14:08:47.69  [PAPPA]
P88_MIMO2.COM;1                  2   1-MAR-1994 16:40:50.81  [PAPPA]
P88_NOISE_1.COM;1                2  27-APR-1993 14:17:34.19  [PAPPA]
P88_PRFS_AF_LSIM.COM;1           2  19-NOV-1993 11:26:04.51  [PAPPA]
P88_PRFS_DF_LSIM.COM;1           2   2-FEB-1994 13:06:10.95  [PAPPA]
P89.COM;1                        2   1-FEB-1994 15:44:05.84  [PAPPA]
P89B.COM;1                       1  26-OCT-1992 10:50:17.94  [PAPPA]
                                 1   1-MAR-1994 14:58:57.17  [PAPPA]
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P89_PRFS_AF_LSIM.COM;1
                        1   2-FEB-1994 12:55:49.86  [PAPPA]
P89_PRFS_DF_LSIM.COM;1
                        1   1-FEB-1994 15:45:48.25  [PAPPA]
P9.COM;1                2  21-JUL-1993 15:25:07.46  [PAPPA]
P90.COM;1               1  19-OCT-1992 14:10:25.67  [PAPPA]
P92.COM;1               1  11-AUG-1993 08:50:33.64  [PAPPA]
P92_DEMO.COM;1          1  19-NOV-1993 15:45:32.76  [PAPPA]
P98.COM;1               1   7-AUG-1992 13:58:49.68  [PAPPA]
P99.COM;1               1  28-JUL-1993 09:50:54.50  [PAPPA]
P99_ALL_DEMO.COM;1      1  10-SEP-1993 11:12:35.25  [PAPPA]
P99_SH1_DEMO.COM;1      1  10-SEP-1993 10:59:22.31  [PAPPA]
P99_SH2_DEMO.COM;1      1  10-SEP-1993 10:59:34.48  [PAPPA]
P99_SH3_DEMO.COM;1      1  10-SEP-1993 10:59:43.75  [PAPPA]
P9_0_100_DEMO.COM;1
                        6  23-NOV-1993 14:26:20.51  [PAPPA]
P9_20_50_DEMO.COM;1
                        5  19-NOV-1993 15:05:01.66  [PAPPA]
RUN_MIMO0.COM;1         3  19-APR-1993 07:59:07.35  [PAPPA]
RUN_MIMO1.COM;1         3  18-JUN-1992 10:11:33.18  [PAPPA]
RUN_SISO1.COM;1         3  16-JUN-1992 09:25:13.52  [PAPPA]
RUN_SISO2.COM;1         5  15-JUN-1992 14:33:33.36  [PAPPA]

Total of 270 files, 607 blocks.

Directory SDBRP$DKA0:[ERA.HELP]

ERROR_MESSAGES.LIS;1
                       20  14-APR-1994 11:03:48.75  [PAPPA]

Total of 1 file, 20 blocks.

Directory SDBRP$DKA0:[ERA.LW]

LW132.COM;1             1   7-DEC-1989 14:12:48.89  [PAPPA]
LW132.EXE;1             8   6-APR-1994 15:57:55.62  [PAPPA]
LW132.FOR;1             5   6-APR-1994 15:57:36.54  [PAPPA]
LW132.OBJ;1             6   6-APR-1994 15:57:42.18  [PAPPA]
LW132UG.EXE;1           7  27-MAY-1992 09:27:46.98  [PAPPA]
LW132UG.FOR;1           4  27-MAY-1992 09:27:08.67  [PAPPA]
LW132UG_CNTRL.COM;1
                        2  15-JUN-1992 08:24:04.31  [PAPPA]
LW132_CNTRL.COM;1       2   6-APR-1994 16:11:08.80  [PAPPA]
LW132_HEADER.DAT;1      5   4-NOV-1992 13:51:34.41  [PAPPA]
LW2COLS.COM;1           1   7-DEC-1989 14:20:49.31  [PAPPA]
LW2COLS.EXE;1           9   7-DEC-1989 14:21:28.30  [PAPPA]
LW2COLS.FOR;1           5   7-NOV-1989 08:21:23.87  [PAPPA]
LW2COLS_CNTRL.COM;1
                        2   7-DEC-1989 14:21:15.06  [PAPPA]
LW2COLS_HEADER.DAT;1
                        3  30-SEP-1989 14:44:00.02  [PAPPA]
LW80.COM;1              1   7-DEC-1989 14:15:54.57  [PAPPA]
LW80.EXE;1              8   7-DEC-1989 14:16:57.62  [PAPPA]
LW80.FOR;1              4  29-SEP-1989 13:10:13.53  [PAPPA]
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LW80DS.COM;1                1   7-DEC-1989 14:19:35.03  [PAPPA]
LW80DS.EXE;1                8   7-DEC-1989 14:19:45.90  [PAPPA]
LW80DS.FOR;1                4  18-SEP-1989 12:39:01.74  [PAPPA]
LW80DS_CNTRL.COM;1          2   7-DEC-1989 14:19:01.41  [PAPPA]
LW80DS_HEADER.DAT;1
                            3  18-SEP-1989 21:30:54.81  [PAPPA]
LW80_CNTRL.COM;1            2   7-DEC-1989 14:16:20.46  [PAPPA]
LW80_HEADER.DAT;1           3  30-SEP-1989 12:00:23.97  [PAPPA]
LW80_NO_FOOTER.COM;1
                            1   7-DEC-1989 14:22:51.18  [PAPPA]
LW80_NO_FOOTER.EXE;1
                            7   7-DEC-1989 14:23:29.90  [PAPPA]
LW80_NO_FOOTER.FOR;1
                            4  29-SEP-1989 17:50:03.99  [PAPPA]
LW80_NO_FOOTER_CNTRL.COM;1
                            2   8-DEC-1989 13:37:06.64  [PAPPA]
LWP.COM;1                   2  20-APR-1994 15:03:44.26  [PAPPA]
LWPICS.COM;1                3   5-FEB-1990 15:33:05.93  [PAPPA]
LWPICS0.COM;1               3  14-FEB-1990 14:01:40.73  [PAPPA]

Total of 31 files, 118 blocks.

Directory SDBRP$DKA0:[ERA.MATLAB]

BUILD_AC_MODAL.M;1          2  10-FEB-1994 11:15:35.19  [PAPPA]
BUILD_AD_MODAL.M;1          2  10-FEB-1994 11:15:39.92  [PAPPA]
ERAM_ORIGINAL.M;1          12   1-JUN-1992 09:50:01.37  [PAPPA]
ERAW.M;1                   15  20-SEP-1993 15:28:10.14  [PAPPA]
ERAW_ORIGINAL.M;1          15  17-SEP-1993 15:42:13.55  [PAPPA]
ERA_WALTER.M;1             13   1-JUN-1992 09:49:51.40  [PAPPA]
FIGS4TO6_THEORY_A.M;1
                            4  14-JAN-1994 15:31:42.42  [PAPPA]
FIGS4TO6_THEORY_D.M;1
                            4  14-JAN-1994 15:31:44.91  [PAPPA]
FROM_SULLA.FOR;1           56  24-JUN-1992 15:23:58.79  [PAPPA]
G1B_DATA_VS_RECON.COM;1
                            4  24-JUN-1993 16:07:18.47  [PAPPA]
G3.COM;1                    2   1-JUL-1993 16:05:06.09  [PAPPA]
HZ_FROM_HS_AND_ZOH.M;1
                           11  19-JAN-1994 16:01:05.75  [PAPPA]
IRFS_AF_THEORY.M;1          8   8-FEB-1994 08:40:55.57  [PAPPA]
IRFS_DF_THEORY.M;1          8   8-FEB-1994 08:40:59.61  [PAPPA]
LSIM_FOH.M;1                6  25-JAN-1994 12:43:32.96  [PAPPA]
LSIM_ZOH.M;1                4  25-JAN-1994 12:43:35.87  [PAPPA]
MATLAB_SUBS.FOR;1           8  30-JUN-1992 09:06:16.13  [PAPPA]
MIMO1.M;1                   3  10-FEB-1994 11:08:23.54  [PAPPA]
MODAL_PAR_THEORY.M;1
                            2  31-JAN-1994 10:50:39.89  [PAPPA]
OKID_PRFS_AF_THEORY.M;1
                            8  10-FEB-1994 09:34:58.92  [PAPPA]
OKID_PRFS_DF_THEORY.M;1
                            8  10-FEB-1994 09:35:01.37  [PAPPA]
P10.COM;1                   2  24-JUN-1993 16:01:44.13  [PAPPA]
P10_IRFS_A_THEORY.COM;1
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                                2   1-JUL-1993 13:03:32.35  [PAPPA]
P10_IRFS_D_THEORY.COM;1
                                2   1-JUL-1993 13:03:13.00  [PAPPA]
P11.COM;1                       2  24-JUN-1993 15:49:30.46  [PAPPA]
P11.OUT;1                       6  29-JUN-1993 10:34:45.25  [PAPPA]
P11_IRFS_A_THEORY.COM;1
                                2   1-JUL-1993 13:05:38.34  [PAPPA]
P11_IRFS_A_THEORY.OUT;1
                                6   1-JUL-1993 13:04:56.33  [PAPPA]
P11_IRFS_D_THEORY.COM;1
                                2   1-JUL-1993 13:04:17.86  [PAPPA]
P76C.COM;1                      1  24-JUN-1993 14:56:15.52  [PAPPA]
P76C_IRFS_A.COM;1               1   1-JUL-1993 12:57:14.70  [PAPPA]
P76C_IRFS_D.COM;1               1   1-JUL-1993 12:55:55.60  [PAPPA]
P76C_PRFS_A.COM;1               1   1-JUL-1993 15:00:17.18  [PAPPA]
P76C_PRFS_D.COM;1               1   1-JUL-1993 14:17:19.60  [PAPPA]
P88.COM;1                       1  24-JUN-1993 16:09:02.29  [PAPPA]
PRFS_AF_THEORY.M;1              6   8-FEB-1994 08:41:16.62  [PAPPA]
PRFS_DF_THEORY.M;1              6   8-FEB-1994 08:41:19.09  [PAPPA]
T1_PRFS1_A_THEORY.DAT;1
                                4   1-JUL-1993 15:00:03.74  [PAPPA]
T1_PRFS2_A_THEORY.DAT;1
                                4   1-JUL-1993 15:00:22.01  [PAPPA]
TEST_MATLAB_WRITE.FOR;1
                               11  29-JUN-1992 15:07:38.54  [PAPPA]

Total of 40 files, 256 blocks.

Directory SDBRP$DKA0:[ERA.MISC]

BATCH_GRAPHICS_DEMO.COM;1
                                2  29-MAY-1992 16:03:06.01  [PAPPA]
TCDUMMY_CC_FILE.DAT;1
                               51   9-AUG-1991 14:25:35.51  [PAPPA]

Total of 2 files, 53 blocks.

Directory SDBRP$DKA0:[ERA.MMST_NAS]

FREQS_AND_DAMPS.DAT;1
                               14   1-SEP-1993 09:34:28.19  [PAPPA]
G1B_23Y.COM;1                   4   2-SEP-1992 10:48:40.70  [PAPPA]
G1B_DEMO.COM;1                  4  15-APR-1992 10:39:06.42  [PAPPA]
G1B_SH1.COM;1                   4   8-SEP-1992 14:48:38.17  [PAPPA]
G25.COM;1                       1   3-APR-1992 16:23:45.41  [PAPPA]
INIT_0_10.ERA;1                 4  20-OCT-1993 15:48:43.04  [PAPPA]
INIT_20_50.ERA;1                4   2-AUG-1993 14:32:14.51  [PAPPA]
INIT_20_50_ANM31.ERA;1
                                4   3-AUG-1993 10:21:47.47  [PAPPA]
INIT_20_50_KD37P3_LO1.ERA;1
                                4   3-AUG-1993 10:31:43.33  [PAPPA]
INIT_20_50_LO1_KD37P3.ERA;1
                                4   3-AUG-1993 10:28:46.07  [PAPPA]
INIT_20_50_LO1_TO100.ERA;1
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                                4  28-FEB-1994 08:44:06.99  [PAPPA]
INIT_20_50_LOOPOP1.ERA;1
                                4  25-FEB-1994 10:04:13.95  [PAPPA]
INIT_20_50_LOOPOP2.ERA;1
                                4   4-AUG-1993 10:17:40.64  [PAPPA]
INIT_20_50_LOOPOP4.ERA;1
                                4   4-NOV-1993 12:45:59.67  [PAPPA]
INIT_20_50_MODELD.ERA;1
                                4  13-SEP-1993 15:37:29.73  [PAPPA]
INIT_50_80.ERA;1                4  20-OCT-1993 15:49:02.72  [PAPPA]
INIT_FIR_20_50.ERA;1
                                4   2-NOV-1993 10:54:08.50  [PAPPA]
INIT_FIR_20_50_IORFIR8.ERA;1
                                4   2-NOV-1993 11:04:41.86  [PAPPA]
JOBDESC_INIT_20_50.DAT;1
                                1  22-SEP-1993 08:31:05.05  [PAPPA]
MMST.LOC;1                      4   5-NOV-1993 09:41:33.17  [PAPPA]
MMST_BLD_DPS.EXE;1              8  30-APR-1992 13:45:25.61  [PAPPA]
MMST_BLD_DPS.FOR;1              5  30-APR-1992 13:45:10.94  [PAPPA]
MMST_BLD_DPS2.EXE;1
                                6  30-APR-1992 11:01:36.32  [PAPPA]
MMST_BLD_DPS_SH1.EXE;1
                                7  30-APR-1992 13:12:42.56  [PAPPA]
MMST_BLD_DPS_SH1.FOR;1
                                4  30-APR-1992 13:12:27.26  [PAPPA]
MMST_BLD_DPS_SH3.EXE;1
                                7  30-APR-1992 13:14:55.22  [PAPPA]
MMST_BLD_DPS_SH3.FOR;1
                                4  30-APR-1992 13:12:02.87  [PAPPA]
MMST_CON.DAT;1                  3  19-NOV-1992 15:19:53.73  [PAPPA]
MMST_CON.UNV;1                  4   5-NOV-1992 12:47:28.54  [PAPPA]
MMST_GEO.DAT;1                  5   5-NOV-1992 10:38:00.88  [PAPPA]
MMST_GEO.UNV;1                  9   5-NOV-1992 12:46:55.20  [PAPPA]
MMST_NASEIGV_42P2HZ_MODE.UNV;1
                               11   1-MAR-1994 09:03:48.68  [PAPPA]
MMST_NASEIGV_900110_TESTDOFS.UNV;1
                             1661   4-NOV-1993 17:09:45.48  [PAPPA]
MMST_NASEIGV_900110_TESTDOFS_GMODES.UNV;1
                              163  24-FEB-1994 13:06:58.98  [PAPPA]
MMST_NAS_0_10_AF.ERA;1
                                4   2-SEP-1992 16:19:26.76  [PAPPA]
MMST_NAS_3_10_AF.ERA;1
                                4   3-SEP-1992 08:53:41.96  [PAPPA]
NAMELIST_INIT_20_50.DAT;1
                                1  22-SEP-1993 08:30:28.99  [PAPPA]
P20_SH1_30_45.COM;1
                                2   8-SEP-1992 14:43:41.17  [PAPPA]
P20_SH2_20_50_DEMO.COM;1
                                2  29-JAN-1993 12:59:34.73  [PAPPA]
P21.COM;1                       2  10-MAR-1993 09:45:24.14  [PAPPA]
P25.COM;1                       3  10-SEP-1992 14:56:01.43  [PAPPA]
P26_1.COM;1                     1   9-SEP-1992 14:27:23.28  [PAPPA]
P26_1_42P2HZ_MODE.COM;1
                                1   1-MAR-1994 09:03:46.69  [PAPPA]
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P26_1_GLOBAL_MODES.COM;1
                              2  24-FEB-1994 13:06:52.48  [PAPPA]
P30_MMST_NAS_22X_0_10_AF.COM;1
                              3   2-SEP-1992 12:52:48.92  [PAPPA]
P30_MMST_NAS_22X_3_10_AF.COM;1
                              3   3-SEP-1992 08:48:06.74  [PAPPA]
P30_MMST_NAS_23Y_0_10_AF.COM;1
                              3   2-SEP-1992 10:51:05.69  [PAPPA]
P30_MMST_NAS_23Y_3_10_AF.COM;1
                              3   3-SEP-1992 08:49:52.43  [PAPPA]
P30_MMST_NAS_24X_0_10_AF.COM;1
                              3   2-SEP-1992 10:53:17.08  [PAPPA]
P30_MMST_NAS_24X_3_10_AF.COM;1
                              3   3-SEP-1992 08:50:42.66  [PAPPA]
P3_SH1_NST5.COM;1             1  31-MAR-1994 10:38:05.88  [PAPPA]
P79_MMST_NAS_0_10_AF.COM;1
                              1   2-SEP-1992 12:50:49.08  [PAPPA]
P79_MMST_NAS_3_10_AF.COM;1
                              1   3-SEP-1992 08:55:19.38  [PAPPA]
T1APS_MIF_DEMO.DAT;1
                             81  25-AUG-1993 10:22:45.76  [PAPPA]
T1NAMES_INIT_20_50.DAT;1
                              1  22-SEP-1993 08:28:41.36  [PAPPA]
T1_MMST_NAS_SH1.DAT;1
                           4169  22-FEB-1994 14:10:43.37  [PAPPA]
T1_MMST_NAS_SH1_NONOISE.DAT;1
                           4169  30-APR-1992 13:45:31.68  [PAPPA]
T1_MMST_NAS_SH1_NONOISE_NST5.UNV;1
                            673  31-MAR-1994 10:38:41.10  [PAPPA]
T1_MMST_NAS_SH2.DAT;1
                           4169  22-FEB-1994 14:11:32.44  [PAPPA]
T1_MMST_NAS_SH2_NONOISE.DAT;1
                           4169  30-APR-1992 13:46:12.10  [PAPPA]
T1_MMST_NAS_SH3.DAT;1
                           4169  22-FEB-1994 14:12:19.15  [PAPPA]
T1_MMST_NAS_SH3_NONOISE.DAT;1
                           4169  30-APR-1992 13:46:53.49  [PAPPA]
TC_MMST_NASTRAN_DOFS.DAT;1
                             13  24-FEB-1994 13:55:05.67  [PAPPA]
TC_MMST_NAS_SH1.DAT;1
                             13  22-FEB-1994 14:10:43.68  [PAPPA]
TC_MMST_NAS_SH1_NONOISE.DAT;1
                             11  27-APR-1992 14:45:58.20  [PAPPA]
TC_MMST_NAS_SH2.DAT;1
                             13  22-FEB-1994 14:11:32.72  [PAPPA]
TC_MMST_NAS_SH2_NONOISE.DAT;1
                             11  27-APR-1992 14:46:05.38  [PAPPA]
TC_MMST_NAS_SH3.DAT;1
                             13  22-FEB-1994 14:12:19.45  [PAPPA]
TC_MMST_NAS_SH3_NONOISE.DAT;1
                             11  27-APR-1992 14:46:12.24  [PAPPA]

Total of 69 files, 27878 blocks.
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Directory SDBRP$DKA0:[ERA.MPLUS]

ADFF.FOR;1                 21  17-OCT-1985 00:00:00.00  [PAPPA]
ADFU.FOR;1                 27  17-OCT-1985 00:00:00.00  [PAPPA]
MP011.DAT;1                 1   4-JAN-1989 20:33:47.16  [PAPPA]
MP025.DAT;1                 5   5-NOV-1987 18:03:34.86  [PAPPA]
MP041.DAT;1                 2  21-NOV-1988 18:11:38.22  [PAPPA]
MP042.DAT;1                 2  21-NOV-1988 18:20:39.36  [PAPPA]
MP049.DAT;1                 5   1-JUN-1988 13:52:01.93  [PAPPA]
NST30.G;1                   5   8-DEC-1987 10:28:53.54  [PAPPA]
NST30.T;1                   6   8-DEC-1987 10:32:29.46  [PAPPA]

Total of 9 files, 74 blocks.

Directory SDBRP$DKA0:[ERA.MX]

MX001.DAT;1                 1   6-DEC-1987 13:07:26.48  [PAPPA]
MX002.DAT;1                 1   1-JUN-1988 13:18:53.14  [PAPPA]
MX005.DAT;1                 2   7-JUN-1989 10:19:16.94  [PAPPA]
MX006.DAT;1                 4  21-SEP-1988 14:34:10.31  [PAPPA]
MX007.DAT;1                 4  21-SEP-1988 14:34:20.09  [PAPPA]
MX034.DAT;1                 4   7-MAR-1988 21:31:59.74  [PAPPA]
MX037.DAT;1                 2  23-SEP-1988 08:57:44.14  [PAPPA]
MXLOG.COM;1                 2  23-SEP-1988 08:58:21.45  [PAPPA]
MXLOG.LIS;1                 1  23-SEP-1988 08:58:43.41  [PAPPA]

Total of 9 files, 21 blocks.

Directory SDBRP$DKA0:[ERA.NONVAX_USAGE]

DEMO.COM;1                  4  24-SEP-1993 11:05:56.90  [PAPPA]
ERA_NONVAX.EXE;1          261  25-APR-1994 09:47:41.99  [PAPPA]
JOBDESC_INIT_20_50.DAT;1
                            1  22-SEP-1993 08:31:05.05  [PAPPA]
NAMELIST_INIT_20_50.DAT;1
                            1  22-SEP-1993 08:30:28.99  [PAPPA]
P82_DEMO.COM;1              1  22-SEP-1993 12:52:24.84  [PAPPA]
T1NAMES_INIT_20_50.DAT;1
                            1  22-SEP-1993 08:28:41.36  [PAPPA]
T1_MMST_NAS_SH1_20_50.DAT;1
                           83  22-SEP-1993 12:52:38.40  [PAPPA]
T1_MMST_NAS_SH2_20_50.DAT;1
                           83  22-SEP-1993 12:52:38.56  [PAPPA]
T1_MMST_NAS_SH3_20_50.DAT;1
                           83  22-SEP-1993 12:52:38.88  [PAPPA]
TC_MMST_NAS_SH1_20_50.DAT;1
                           11  25-AUG-1993 11:25:34.39  [PAPPA]
TC_MMST_NAS_SH2_20_50.DAT;1
                           11  25-AUG-1993 11:26:48.35  [PAPPA]
TC_MMST_NAS_SH3_20_50.DAT;1
                           11  25-AUG-1993 11:28:03.08  [PAPPA]

Total of 12 files, 551 blocks.
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Directory SDBRP$DKA0:[ERA.OBJS]

ADFF.OBJ;1                    8  29-OCT-1989 17:02:41.35  [PAPPA]
ADFU.OBJ;1                   12  29-OCT-1989 17:02:44.12  [PAPPA]
ERAMLB.OBJ;1                 46  28-SEP-1993 15:53:56.97  [PAPPA]
ERAMLB_910725.OBJ;1
                             46  25-JUL-1991 11:14:18.79  [PAPPA]
ERAP1.OBJ;1                  61  31-OCT-1990 14:53:48.72  [PAPPA]
ERAP1B.OBJ;1                 42  31-OCT-1990 15:01:35.48  [PAPPA]
ERASUBS.OBJ;1               302  13-APR-1994 14:25:12.58  [PAPPA]
ERASYS_VAX.OBJ;1              1  17-SEP-1992 14:14:43.33  [PAPPA]
FIRLB.OBJ;1                   3  21-SEP-1993 16:26:10.64  [PAPPA]
FTANDP.OBJ;1                 17   7-APR-1994 13:56:53.99  [PAPPA]
LOADMAT.OBJ;1                 2  17-AUG-1992 16:30:04.33  [PAPPA]
MSAVE.OBJ;1                   7  18-AUG-1992 09:19:12.72  [PAPPA]
READMAT.OBJ;1                 2  17-AUG-1992 14:41:55.41  [PAPPA]
RSPGRA.OLB;1                 63   9-JUL-1993 14:56:34.13  [PAPPA]
RSPLIB.OLB;1                 60  28-OCT-1993 11:22:34.57  [PAPPA]
RTPE79.OBJ;1                  4  24-NOV-1992 16:26:57.49  [PAPPA]
RTPE85.OBJ;1                  6   2-APR-1993 14:40:11.52  [PAPPA]
SAVEMAT.OBJ;1                 3  30-JUN-1992 10:01:21.03  [PAPPA]
SFT.OBJ;1                    12  17-SEP-1992 14:17:00.93  [PAPPA]
WMATXX.OBJ;1                  3  14-JUL-1993 16:29:04.24  [PAPPA]

Total of 20 files, 700 blocks.

Directory SDBRP$DKA0:[ERA.OPTIONS]

G15_OPTIONS.DAT;1             1   4-NOV-1993 17:16:41.40  [PAPPA]
G15_OPTIONS_DEMO.DAT;1
                              1  25-FEB-1994 08:22:26.76  [PAPPA]
G1_OPTIONS_BORDER.DAT;1
                              1  22-OCT-1993 08:57:20.11  [PAPPA]
G50_OPTIONS.DAT;1             1   2-APR-1993 15:19:03.60  [PAPPA]
G5_OPTIONS.DAT;1              1   8-APR-1993 13:01:48.72  [PAPPA]
G7_OPTIONS.DAT;1              1  27-OCT-1993 14:36:38.04  [PAPPA]
G7_OPTIONS_DEMO.DAT;1
                              1  25-FEB-1994 08:22:11.51  [PAPPA]
P10B_OPTIONS.DAT;1            1  24-NOV-1992 16:19:43.32  [PAPPA]
P20_OPTIONS.DAT;1             1  28-JAN-1993 15:11:46.50  [PAPPA]
P26_8_OPTIONS.DAT;1
                              1  19-FEB-1993 13:47:20.62  [PAPPA]
P30_OPTIONS.DAT;1             1   2-SEP-1992 08:43:53.61  [PAPPA]

Total of 11 files, 11 blocks.

Directory SDBRP$DKA0:[ERA.OTHER_EXAMPLES]

EX001.COM;1                   1  25-MAR-1994 08:53:50.92  [PAPPA]
EX002.COM;1                   2  25-MAR-1994 08:54:02.87  [PAPPA]
EX003.COM;1                   3  25-MAR-1994 08:54:15.27  [PAPPA]
EX004.COM;1                   2  22-MAR-1994 13:19:12.71  [PAPPA]
EX005.COM;1                   2  22-MAR-1994 13:20:23.23  [PAPPA]
EX006.COM;1                   2  21-MAR-1994 14:24:51.99  [PAPPA]
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EX006_IC2.COM;1              2  21-MAR-1994 14:27:14.95  [PAPPA]
EX007.COM;1                  1  23-MAR-1994 11:28:04.50  [PAPPA]
EX008.COM;1                  2  31-MAR-1994 09:16:53.72  [PAPPA]
EX009.COM;1                  2  21-APR-1994 12:41:17.89  [PAPPA]
EX010.COM;1                  1  20-APR-1994 10:37:32.97  [PAPPA]
EX011.COM;1                  2  24-MAR-1994 11:22:20.17  [PAPPA]
EX012.COM;1                  2  20-APR-1994 13:41:15.58  [PAPPA]
EX013.COM;1                  1  24-MAR-1994 14:34:46.87  [PAPPA]
EX014.COM;1                  2  21-MAR-1994 09:34:43.67  [PAPPA]
EX015.COM;1                  2  21-APR-1994 08:20:40.18  [PAPPA]
EX016.COM;1                  2  13-APR-1994 13:22:06.02  [PAPPA]
EX017.COM;1                  2  21-APR-1994 10:27:38.98  [PAPPA]
EX1.ERA;1                    3  17-MAR-1994 15:08:53.46  [PAPPA]
EX10.ERA;1                   3  20-APR-1994 10:39:56.84  [PAPPA]
EX11.ERA;1                   3  24-MAR-1994 11:20:53.74  [PAPPA]
EX12.ERA;1                   3  24-MAR-1994 13:59:09.53  [PAPPA]
EX13.ERA;1                   3  24-MAR-1994 14:16:08.11  [PAPPA]
EX14.ERA;1                   3  21-MAR-1994 09:14:33.66  [PAPPA]
EX15.ERA;1                   4  21-APR-1994 08:37:08.25  [PAPPA]
EX16.ERA;1                   3  21-APR-1994 10:16:54.91  [PAPPA]
EX17.ERA;1                   3  20-APR-1994 14:41:17.20  [PAPPA]
EX2.ERA;1                    3  17-MAR-1994 15:49:57.03  [PAPPA]
EX3.ERA;1                    3  18-MAR-1994 15:37:01.99  [PAPPA]
EX4.ERA;1                    3  28-MAR-1994 10:57:19.33  [PAPPA]
EX5.ERA;1                    3  28-MAR-1994 14:22:43.26  [PAPPA]
EX6.ERA;1                    3  28-MAR-1994 10:59:19.71  [PAPPA]
EX6_IC2.ERA;1                3  21-MAR-1994 14:29:47.94  [PAPPA]
EX7.ERA;1                    3  29-MAR-1994 15:19:49.22  [PAPPA]
EX8.ERA;1                    3  19-APR-1994 15:51:40.27  [PAPPA]
EX9.ERA;1                    3  20-APR-1994 08:08:42.27  [PAPPA]
EXLOG.COM;1                  2  14-MAR-1994 12:55:47.65  [PAPPA]
EXLOG.LIS;1                  2  21-MAR-1994 09:36:40.40  [PAPPA]
MIMO.LOC;1                   2  28-MAR-1994 11:08:04.61  [PAPPA]
P25_EX6.COM;1                3  28-MAR-1994 11:17:06.13  [PAPPA]

Total of 40 files, 97 blocks.

Directory SDBRP$DKA0:[ERA.QA]

QA_RUN_SISO1.COM;1           2  10-SEP-1989 16:02:57.25  [PAPPA]
QA_RUN_SISO2.COM;1           4  10-SEP-1989 15:57:38.60  [PAPPA]
QA_SISO1.ERA;1               4   5-SEP-1989 19:05:27.23  [PAPPA]
QA_SISO2.ERA;1               4  31-AUG-1989 13:48:05.67  [PAPPA]

Total of 4 files, 14 blocks.

Directory SDBRP$DKA0:[ERA.SOURCES]

AVG_SPECTRUM_MAG.FOR;1
                             4  12-AUG-1991 14:05:35.16  [PAPPA]
BUILD_DUMMY_CC_FILE.FOR;1
                             2   9-AUG-1991 14:25:19.97  [PAPPA]
BUILD_MMST_GEO.FOR;1
                             2   5-NOV-1992 10:37:44.31  [PAPPA]
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C.COM;1                    1   9-MAR-1990 15:25:53.66  [PAPPA]
EPS.COM;1                  1  14-AUG-1991 10:00:45.02  [PAPPA]
EPS.FOR;1                  2  22-SEP-1993 15:00:49.95  [PAPPA]
ERAG1.FOR;1               79   7-APR-1994 13:55:36.95  [PAPPA]
ERAG10.FOR;1              10  13-JUL-1993 10:33:57.91  [PAPPA]
ERAG15.FOR;1             113  21-APR-1994 10:49:19.40  [PAPPA]
ERAG2.FOR;1               18  13-JUL-1993 10:14:05.56  [PAPPA]
ERAG25.FOR;1              68  13-JUL-1993 10:35:25.89  [PAPPA]
ERAG26.FOR;1              20  13-JUL-1993 10:36:41.24  [PAPPA]
ERAG2B.FOR;1              22  14-OCT-1993 10:38:34.92  [PAPPA]
ERAG2C.FOR;1              20  13-JUL-1993 10:21:04.88  [PAPPA]
ERAG2_3D.FOR;1            13  13-DEC-1989 17:05:24.98  [PAPPA]
ERAG3.FOR;1               26   7-APR-1994 14:02:25.11  [PAPPA]
ERAG3B.FOR;1              20   7-APR-1994 14:04:58.91  [PAPPA]
ERAG4.FOR;1               34   1-NOV-1993 15:21:00.89  [PAPPA]
ERAG5.FOR;1               74  13-APR-1994 15:47:24.25  [PAPPA]
ERAG50.FOR;1             121   7-APR-1994 15:11:18.61  [PAPPA]
ERAG5B.FOR;1              36  13-JUL-1993 10:31:57.40  [PAPPA]
ERAG6.FOR;1               20  13-JUL-1993 10:32:57.40  [PAPPA]
ERAG7.FOR;1               79   7-APR-1994 13:56:00.33  [PAPPA]
ERAG92.FOR;1              20  19-NOV-1993 15:52:05.49  [PAPPA]
ERAMAIN.FOR;1             33  13-APR-1994 14:27:59.36  [PAPPA]
ERAMLB.FOR;1             309  28-SEP-1993 15:53:45.48  [PAPPA]
ERAP0.FOR;1                8   6-AUG-1993 11:20:35.38  [PAPPA]
ERAP0B.FOR;1               5  28-JUN-1993 08:34:30.92  [PAPPA]
ERAP1.FOR;1              160  31-OCT-1990 14:52:49.24  [PAPPA]
ERAP10.FOR;1              58   2-MAR-1994 14:24:11.56  [PAPPA]
ERAP10B.FOR;1             40   1-MAR-1994 16:39:31.23  [PAPPA]
ERAP10C.FOR;1             18  19-APR-1994 15:19:08.68  [PAPPA]
ERAP11.FOR;1              40   8-SEP-1993 13:21:25.78  [PAPPA]
ERAP125.FOR;1             29  12-JUL-1993 09:38:41.39  [PAPPA]
ERAP1B.FOR;1             106  31-OCT-1990 14:55:50.59  [PAPPA]
ERAP2.FOR;1               26  31-MAR-1994 10:31:22.61  [PAPPA]
ERAP20.FOR;1              20  11-APR-1994 09:53:39.37  [PAPPA]
ERAP21.FOR;1              10   6-JUL-1993 08:58:32.19  [PAPPA]
ERAP24.FOR;1              21  10-MAR-1993 09:22:38.15  [PAPPA]
ERAP24B.FOR;1              8  23-JUL-1993 14:42:57.16  [PAPPA]
ERAP25.FOR;1              87  30-AUG-1993 14:01:18.90  [PAPPA]
ERAP26.FOR;1              17  14-APR-1994 13:08:33.24  [PAPPA]
ERAP27.FOR;1               4   2-NOV-1992 14:08:07.39  [PAPPA]
ERAP2B.FOR;1              14  30-MAR-1993 09:07:18.17  [PAPPA]
ERAP2C.FOR;1              13  30-OCT-1991 16:17:48.60  [PAPPA]
ERAP2D.FOR;1              18  27-NOV-1991 13:50:32.41  [PAPPA]
ERAP3.FOR;1               12   5-MAR-1992 12:46:43.00  [PAPPA]
ERAP30.FOR;1              44  19-APR-1994 10:53:13.20  [PAPPA]
ERAP3B.FOR;1              10   1-NOV-1990 12:37:26.86  [PAPPA]
ERAP3C.FOR;1               7  30-OCT-1991 13:59:16.46  [PAPPA]
ERAP4.FOR;1               18   7-APR-1994 08:58:01.86  [PAPPA]
ERAP40.FOR;1              28  27-NOV-1991 15:45:20.41  [PAPPA]
ERAP5.FOR;1               10   7-APR-1994 08:25:03.59  [PAPPA]
ERAP50.FOR;1              10  10-MAY-1990 11:54:14.14  [PAPPA]
ERAP6.FOR;1                3  31-MAR-1993 09:16:23.69  [PAPPA]
ERAP70.FOR;1              11  23-OCT-1992 11:28:03.34  [PAPPA]
ERAP75A.FOR;1              8  30-JUN-1992 13:10:49.14  [PAPPA]
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ERAP75B.FOR;1                8  29-MAR-1993 10:15:24.21  [PAPPA]
ERAP76A.FOR;1                8  20-SEP-1993 16:30:14.59  [PAPPA]
ERAP76B.FOR;1               10  27-JUL-1993 14:03:21.93  [PAPPA]
ERAP76C.FOR;1                6  25-JAN-1994 09:27:10.87  [PAPPA]
ERAP79.FOR;1                 4   7-JUN-1993 14:04:32.68  [PAPPA]
ERAP79_DEC_UNIX.FOR;1
                             5  12-NOV-1993 12:01:05.38  [PAPPA]
ERAP80.FOR;1                 4  26-OCT-1992 11:50:47.63  [PAPPA]
ERAP81.FOR;1                 6  22-SEP-1993 09:09:08.19  [PAPPA]
ERAP82.FOR;1                 4  22-SEP-1993 09:18:11.39  [PAPPA]
ERAP85.FOR;1                 4  27-JUL-1992 16:36:17.59  [PAPPA]
ERAP85B.FOR;1                7   8-JUL-1993 13:50:04.07  [PAPPA]
ERAP88.FOR;1                12  24-MAR-1994 10:42:51.29  [PAPPA]
ERAP89.FOR;1                 6  26-OCT-1992 10:49:25.78  [PAPPA]
ERAP89B.FOR;1                5   1-MAR-1994 15:02:07.27  [PAPPA]
ERAP9.FOR;1                 28  19-NOV-1993 15:11:56.98  [PAPPA]
ERAP90.FOR;1                 7  19-OCT-1992 14:17:45.04  [PAPPA]
ERAP91.FOR;1                 6   9-APR-1993 13:09:27.07  [PAPPA]
ERAP92.FOR;1                 8   5-NOV-1993 16:57:20.33  [PAPPA]
ERAP98.FOR;1                 8   7-AUG-1992 13:56:34.11  [PAPPA]
ERAP99.FOR;1                10  19-NOV-1993 11:46:25.10  [PAPPA]
ERASUBS.FOR;1               545 21-APR-1994 08:36:30.58  [PAPPA]
ERASYS.FOR;1                 4  22-SEP-1993 15:05:33.35  [PAPPA]
ERASYS_NONVAX.FOR;1
                             3  22-SEP-1993 15:05:46.13  [PAPPA]
ERASYS_UNIX.FOR;1            3  22-SEP-1993 15:08:16.02  [PAPPA]
ET.FOR;1                     1  12-AUG-1991 08:41:19.99  [PAPPA]
FIRLB.FOR;1                  8  21-SEP-1993 16:26:08.23  [PAPPA]
FLOADSAV.C;1                23  12-NOV-1993 14:12:56.27  [PAPPA]
FSHIFT.FOR;1                 4  18-MAR-1993 09:35:22.02  [PAPPA]
FTANDP.FOR;1                34   7-APR-1994 09:35:56.20  [PAPPA]
LOADMAT.FOR;1                5  17-AUG-1992 16:30:00.56  [PAPPA]
MAC.FOR;1                    3   7-APR-1992 09:46:55.92  [PAPPA]
MIET2.FOR;1                  2  13-AUG-1993 11:36:04.03  [PAPPA]
MIET2B.FOR;1                 2  20-AUG-1993 10:25:27.54  [PAPPA]
MIET3.FOR;1                 14  16-AUG-1993 10:22:28.63  [PAPPA]
MIMO.FOR;1                  23  31-MAR-1994 09:20:04.02  [PAPPA]
MMST_BLD_DPS.FOR;1           5   2-SEP-1992 10:21:15.41  [PAPPA]
MMST_BLD_DPS2.FOR;1
                             3  29-APR-1992 10:58:10.46  [PAPPA]
MMST_BLD_DPS_SH1.FOR;1
                             4  30-APR-1992 13:12:27.26  [PAPPA]
MMST_BLD_DPS_SH3.FOR;1
                             4  30-APR-1992 13:12:02.87  [PAPPA]
MSAVE.C;1                   18  18-AUG-1992 09:18:47.66  [PAPPA]
NOISED.FOR;1                36  15-OCT-1992 15:50:23.00  [PAPPA]
P26_BUILD_MAP.FOR;1
                             7   2-JUN-1993 13:58:49.88  [PAPPA]
P26_DATASETS_LIST.FOR;1
                             4   3-JUN-1993 13:29:23.26  [PAPPA]
P26_DELETE_ROTS.FOR;1
                             7   9-APR-1993 10:11:40.36  [PAPPA]
P26_FREQ_LIST.FOR;1
                            14  11-APR-1994 14:27:58.64  [PAPPA]
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P26_FREQ_SORT.FOR;1
                     15  16-MAY-1991 14:32:21.56  [PAPPA]
P26_LIST.FOR;1        7  26-FEB-1990 08:34:08.01  [PAPPA]
P26_MAT_MERGE.FOR;1
                      8  15-MAR-1990 13:00:46.93  [PAPPA]
P26_MODE_DELETE.FOR;1
                      8  14-APR-1994 13:10:54.77  [PAPPA]
P26_MODE_EXTRACT.FOR;1
                     18   8-APR-1994 08:51:34.56  [PAPPA]
P26_MPC_CALC.FOR;1   28   2-MAY-1991 11:34:31.08  [PAPPA]
P26_NODE_EXTRACT.FOR;1
                     15   1-APR-1993 10:20:54.19  [PAPPA]
P26_NODE_LIST.FOR;1
                      5  23-OCT-1992 16:04:16.27  [PAPPA]
P26_RECORD_LIST.FOR;1
                      7   7-APR-1994 14:41:16.15  [PAPPA]
P26_RENUMBER_MODES.FOR;1
                      7  13-APR-1994 10:15:22.05  [PAPPA]
P26_SCALE_WN.FOR;1    9  16-MAR-1993 10:02:39.00  [PAPPA]
P26_SKEWED_DOF.FOR;1
                     11   4-NOV-1993 16:58:50.97  [PAPPA]
RSPGRA.FOR;1         20   9-JUL-1993 14:56:23.38  [PAPPA]
RSPLIB.FOR;1         11  28-OCT-1993 11:22:29.12  [PAPPA]
RTPE79.FOR;1          5  24-NOV-1992 16:26:48.69  [PAPPA]
RTPE85.FOR;1          7   7-APR-1994 13:54:05.89  [PAPPA]
SAVEMAT.FOR;1         8  17-AUG-1992 09:13:12.77  [PAPPA]
SFT.FOR;1            28   6-SEP-1989 21:40:19.45  [PAPPA]
SIMDATA.FOR;1         2   7-NOV-1991 14:33:56.49  [PAPPA]
SISO.FOR;1            7  15-MAR-1994 10:10:31.58  [PAPPA]
SUM.FOR;1             3  12-NOV-1989 17:50:10.07  [PAPPA]
T2G.DAT;1             0  10-MAR-1994 09:10:49.77  [PAPPA]
TESTLS.FOR;1          6  18-AUG-1992 09:26:45.36  [PAPPA]
WMATXX.FOR;1          3  14-JUL-1993 16:26:57.08  [PAPPA]
WTPE88.FOR;1         13   7-OCT-1991 16:27:28.27  [PAPPA]

Total of 127 files, 3193 blocks.

Directory SDBRP$DKA0:[ERA.TESTCASES]

DATA_VS_RECON_MIMO2.DAT;1
                    482   9-MAR-1994 13:26:45.50  [PAPPA]
JOBDESC_MIMO2.DAT;1
                      1  22-SEP-1993 15:32:52.16  [PAPPA]
MIMO0.ERA;1           4  19-APR-1993 08:16:12.71  [PAPPA]
MIMO0_KD1.ERA;1       4  19-APR-1993 08:14:49.85  [PAPPA]
MIMO1.ERA;1           3  15-MAR-1994 15:57:55.48  [PAPPA]
MIMO1_IORDTU4.ERA;1
                      4  15-MAR-1994 15:40:08.50  [PAPPA]
MIMO1_IORDTU6.ERA;1
                      4  15-MAR-1994 14:45:07.20  [PAPPA]
MIMO1_NONOISE.ERA;1
                      4  21-JAN-1994 10:57:44.90  [PAPPA]
MIMO2.ERA;1           4  15-MAR-1994 15:58:05.43  [PAPPA]
MIMO2_IORDTU6.ERA;1
```

```
                          4  16-MAR-1994 08:39:01.64  [PAPPA]
NAMELIST_MIMO2.DAT;1
                          1  22-SEP-1993 15:32:26.03  [PAPPA]
RUN_MIMO0.COM;1           3  19-APR-1993 07:59:07.35  [PAPPA]
RUN_MIMO1.COM;1           3  18-JUN-1992 10:11:33.18  [PAPPA]
RUN_MIMO1_NONOISE.COM;1
                          3  21-JAN-1994 10:58:56.75  [PAPPA]
RUN_SISO1.COM;1           3  10-MAR-1994 10:59:06.57  [PAPPA]
RUN_SISO2.COM;1           5  15-JUN-1992 14:33:33.36  [PAPPA]
SISO1.ERA;1               3  10-MAR-1994 10:23:38.79  [PAPPA]
SISO2.ERA;1               3  15-MAR-1994 15:57:42.03  [PAPPA]

Total of 18 files, 538 blocks.

Directory SDBRP$DKA0:[ERA.USERS]

ARMAND.;1                 1  20-OCT-1993 09:42:36.83  [PAPPA]
AUGENSTEIN.;1             1  11-SEP-1990 16:20:53.51  [PAPPA]
BASSO.;1                  1  11-SEP-1990 16:21:07.04  [PAPPA]
BLELLOCH.;1               1  11-SEP-1990 16:21:21.16  [PAPPA]
BRESKMAN.;1               1   4-MAR-1992 10:44:36.14  [PAPPA]
CALAPODAS.;1              1  11-SEP-1990 16:21:36.73  [PAPPA]
CHAPMAN.;1                1  11-SEP-1990 16:21:48.01  [PAPPA]
CHEN.;1                   1  11-SEP-1990 16:22:00.61  [PAPPA]
CHUNG.;1                  1  11-SEP-1990 16:22:25.80  [PAPPA]
COLLINS.;1                1  11-SEP-1990 16:22:38.87  [PAPPA]
CROWLEY.;1                1  21-SEP-1993 15:34:45.58  [PAPPA]
DAS.;1                    1  11-SEP-1990 16:22:51.42  [PAPPA]
DILLEY.;1                 1  11-SEP-1990 16:23:02.00  [PAPPA]
GOLD.;1                   1  11-SEP-1990 16:33:39.79  [PAPPA]
GOODNIGHT.;1              1  11-SEP-1990 16:23:17.83  [PAPPA]
GRAYSTON.;1               1  11-SEP-1990 16:42:08.31  [PAPPA]
GRONET.;1                 1  11-SEP-1990 16:23:34.02  [PAPPA]
HAMILTON.;1               1   2-SEP-1993 09:06:11.16  [PAPPA]
HERSHFELD.;1              1  12-MAY-1992 08:29:44.77  [PAPPA]
HOLLKAMP.;1               1  11-SEP-1990 16:23:53.99  [PAPPA]
HOSKINS.;1                1  30-JUL-1993 14:18:50.96  [PAPPA]
IZADPANAH.;1              1  12-SEP-1990 09:52:08.51  [PAPPA]
KETCHUM.;1                1  11-SEP-1990 16:40:12.22  [PAPPA]
KIENHOLZ.;1               1  11-SEP-1990 16:24:05.90  [PAPPA]
KIM.;1                    1  30-NOV-1992 15:15:00.00  [PAPPA]
KODIYALAM.;1              1   1-APR-1993 14:51:49.53  [PAPPA]
KOSUT.;1                  1  11-SEP-1990 15:58:28.88  [PAPPA]
MCCUE.;1                  1  12-SEP-1990 11:43:54.01  [PAPPA]
MEHRA.;1                  1  11-SEP-1990 16:27:02.27  [PAPPA]
NORRIS.;1                 1  12-SEP-1990 12:46:35.83  [PAPPA]
PARK.;1                   1  12-SEP-1990 09:58:04.06  [PAPPA]
PETERSON.;1               1  11-SEP-1990 16:27:47.89  [PAPPA]
PINSON.;1                 1  11-SEP-1990 16:27:59.71  [PAPPA]
RAMAKRISHNAN.;1           1  25-SEP-1990 13:08:20.77  [PAPPA]
RATAN.;1                  1  20-AUG-1993 12:47:16.84  [PAPPA]
RUSSELL.;1                1  12-SEP-1990 09:49:12.66  [PAPPA]
SCHENK.;1                 1   5-OCT-1990 16:13:19.08  [PAPPA]
SIMONIAN.;1               1  11-SEP-1990 16:28:11.32  [PAPPA]
```

```
SINGHAL.;1                    1   2-NOV-1992 09:00:57.26  [PAPPA]
SLATER.;1                     1  12-SEP-1990 11:11:30.34  [PAPPA]
STROUD.;1                     1  22-MAR-1994 09:11:27.79  [PAPPA]
THI.;1                        1  19-OCT-1990 13:50:41.75  [PAPPA]
TURNER.;1                     1  11-SEP-1990 16:20:38.38  [PAPPA]
VAHDATI.;1                    1  29-MAY-1992 13:13:12.44  [PAPPA]
VOELKER.;1                    1  12-SEP-1990 09:41:08.08  [PAPPA]
ZAVODNEY.;1                   1  11-SEP-1990 16:36:20.27  [PAPPA]

Total of 46 files, 46 blocks.

Directory SDBRP$DKA0:[ERA.UTIL]

BATCHBB.COM;1                 1   2-APR-1993 13:43:25.63  [PAPPA]
BATCHRP.COM;1                 1   2-APR-1993 13:43:44.40  [PAPPA]
DELPS.COM;1                   1  26-OCT-1990 10:52:45.13  [PAPPA]
PSDC.COM;1                    1  28-MAY-1992 15:11:13.81  [PAPPA]
PSHR.COM;1                    1  15-APR-1993 13:48:09.11  [PAPPA]
PSNY.COM;1                    1  12-APR-1994 09:52:15.66  [PAPPA]
PSRSM.COM;1                   1  28-MAY-1992 09:56:27.96  [PAPPA]
PS_TALL_FOR099.DAT;1
                              1  29-MAY-1992 11:27:05.99  [PAPPA]
PS_WIDE_FOR099.DAT;1
                              1  29-MAY-1992 11:01:07.90  [PAPPA]
SAVEPS.COM;1                  1  26-FEB-1992 13:40:19.02  [PAPPA]
SDGO.COM;1                    1  14-SEP-1990 13:57:57.17  [PAPPA]

Total of 11 files, 11 blocks.

Grand total of 22 directories, 1313 files, 43140 blocks.
```

APPENDIX G - NON-VAX USAGE

```
$! ERA$NONVAX:DEMO.COM
$!
$! THIS IS A SIMPLE PROCEDURE FILE THAT RUNS ERA WITHOUT
$! ALL THE COMPLICATIONS ASSOCIATED WITH ERA.COM AND ERA_MASTER.COM.
$!
$! ANYONE WITH A BASIC KNOWLEDGE OF VMS DCL COMMANDS (I.E., ANYONE
$! WHO UNDERSTANDS ALL OF THE SIMPLE COMMANDS IN THIS FILE),
$! SHOULD BE ABLE TO EASILY MODIFY THIS PROCEDURE FILE TO RUN ERA
$! ON OTHER COMPUTER SYSTEMS.
$!
$! THIS PROCEDURE FILE RUNS THE MINI-MAST DEMONSTRATION PROBLEM
$! (JOB INIT_20_50) DISCUSSED IN CHAPTER 3 OF THE ERA USER'S GUIDE.
$!
$!  R. PAPPA   9-21-93
$!
$ SET VERIFY
$!
$ DELETE/LOG %%_OUTPUT_FILE.LIS;*
$!
$ COPY/LOG ERA$SOURCES:ERAMAIN.FOR,ERASUBS.FOR,ERAMLB.FOR,ERASYS_NONVAX *
$!
$! * * * SET ARRAY DIMENSIONS * * *
$!       --------------------
$ EDIT/EDT/NOCOMMAND ERAMAIN.FOR
T'PARAMETER (MCH='
S/MCH=/MCH=81/
S/MRH=/MRH=520/
S/MIC=/MIC=3/
S/MST=/MST=104/
S/MTIM=/MTIM=100/
EXIT
$!
$ FORTRAN/CHECK=(BOUNDS,OVERFLOW)/STANDARD=ALL ERAMAIN
$ FORTRAN/CHECK=(BOUNDS,OVERFLOW)/STANDARD=ALL ERASUBS
$ FORTRAN/CHECK=(BOUNDS,OVERFLOW)/STANDARD=ALL ERAMLB
$ FORTRAN/CHECK=(BOUNDS,OVERFLOW)/STANDARD=ALL ERASYS_NONVAX
$!
$ LINK/EXE=ERA_NONVAX ERAMAIN,ERASUBS,ERAMLB,ERASYS_NONVAX
$!
$ DELETE *.FOR;*
$ DELETE *.OBJ;*
$!
$ COPY ERA$MMST_NAS:T1NAMES_INIT_20_50.DAT  70_INPUT_FILE.DAT
$ COPY ERA$HELP:ERROR_MESSAGES.LIS          75_INPUT_FILE.DAT
$ COPY ERA$MMST_NAS:NAMELIST_INIT_20_50.DAT 77_INPUT_FILE.DAT
$ COPY ERA$MMST_NAS:JOBDESC_INIT_20_50.DAT  90_INPUT_FILE.DAT
$!
$ ASSIGN/USER 70_INPUT_FILE.DAT FOR070
$ ASSIGN/USER 75_INPUT_FILE.DAT FOR075
```

```
$ ASSIGN/USER 77_INPUT_FILE.DAT FOR077
$ ASSIGN/USER 90_INPUT_FILE.DAT FOR090
$!
$ ASSIGN/USER 50_OUTPUT_FILE.LIS FOR050
$ ASSIGN/USER 51_OUTPUT_FILE.LIS FOR051
$ ASSIGN/USER 55_OUTPUT_FILE.LIS FOR055
$ ASSIGN/USER 79_OUTPUT_FILE.LIS FOR079
$ ASSIGN/USER 85_OUTPUT_FILE.LIS FOR085
$ ASSIGN/USER 88_OUTPUT_FILE.LIS FOR088
$!
$ RUN ERA_NONVAX
$!
$ PURGE
$!
$ DIRECTORY/SIZE *_OUTPUT_FILE.*
$!
$ SET NOVERIFY
```

The following information appears on your computer screen when DEMO.COM is run:

```
$!
$ DELETE/LOG %%_OUTPUT_FILE.LIS;*
%DELETE-W-SEARCHFAIL, error searching for SDBRP$DKA0:[ERA.NONVAX_USAGE]%%_OUTPUT_F
-RMS-E-FNF, file not found
$!
$ COPY/LOG ERA$SOURCES:ERAMAIN.FOR,ERASUBS.FOR,ERAMLB.FOR,ERASYS_NONVAX *
%COPY-S-COPIED, SDBRP$DKA0:[ERA.SOURCES]ERAMAIN.FOR;1 copied to
SDBRP$DKA0:[ERA.NONVAX_USAGE]ERAMAIN.FOR;1 (33 blocks)
%COPY-S-COPIED, SDBRP$DKA0:[ERA.SOURCES]ERASUBS.FOR;1 copied to
SDBRP$DKA0:[ERA.NONVAX_USAGE]ERASUBS.FOR;1 (545 blocks)
%COPY-S-COPIED, SDBRP$DKA0:[ERA.SOURCES]ERAMLB.FOR;1 copied to
SDBRP$DKA0:[ERA.NONVAX_USAGE]ERAMLB.FOR;1 (309 blocks)
%COPY-S-COPIED, SDBRP$DKA0:[ERA.SOURCES]ERASYS_NONVAX.FOR;1 copied to
SDBRP$DKA0:[ERA.NONVAX_USAGE]ERASYS_NONVAX.FOR;1 (3 blocks)
%COPY-S-NEWFILES, 4 files created
$!
$! * * * SET ARRAY DIMENSIONS * * *
$!       --------------------
$ EDIT/EDT/NOCOMMAND ERAMAIN.FOR
    1              PROGRAM EMAIN
T'PARAMETER (MCH='
   43              PARAMETER (MCH= , MRH= , MIC= , MST= , MTIM= )
S/MCH=/MCH=81/
   43              PARAMETER (MCH=81 , MRH= , MIC= , MST= , MTIM= )
1 substitution
S/MRH=/MRH=520/
   43              PARAMETER (MCH=81 , MRH=520 , MIC= , MST= , MTIM= )
1 substitution
S/MIC=/MIC=3/
   43              PARAMETER (MCH=81 , MRH=520 , MIC=3 , MST= , MTIM= )
1 substitution
S/MST=/MST=104/
   43              PARAMETER (MCH=81 , MRH=520 , MIC=3 , MST=104 , MTIM= )
```

```
1 substitution
S/MTIM=/MTIM=100/
   43              PARAMETER (MCH=81 , MRH=520 , MIC=3 , MST=104 , MTIM=100 )
1 substitution
EXIT
SDBRP$DKA0:[ERA.NONVAX_USAGE]ERAMAIN.FOR;2 544 lines
$!
$ FORTRAN/CHECK=(BOUNDS,OVERFLOW)/STANDARD=ALL ERAMAIN
%FORT-I-EXT_SYN, Extension to FORTRAN-77: Nonstandard syntax
        [=MAX(MRH,MCH),] in module EMAIN at line 45
%FORT-I-EXT_SYN, Extension to FORTRAN-77: Nonstandard syntax
        [T=MIN(MRH,MCH))] in module EMAIN at line 45
%FORT-I-EXT_STMT, Extension to FORTRAN-77: Nonstandard statement type
        [NAMELIST] in module EMAIN at line 138
%FORT-I-ENDDIAGS, SDBRP$DKA0:[ERA.NONVAX_USAGE]ERAMAIN.FOR;2 completed with 3 diag
$ FORTRAN/CHECK=(BOUNDS,OVERFLOW)/STANDARD=ALL ERASUBS
%FORT-I-EXT_STMT, Extension to FORTRAN-77: Nonstandard statement type
        [NAMELIST] in module ERA at line 104
%FORT-I-EXT_STMT, Extension to FORTRAN-77: Nonstandard statement type
        [NAMELIST] in module ERA at line 121
%FORT-I-EXT_KEY, Extension to FORTRAN-77: Nonstandard keyword
        [OLD',READONLY] in module HANKEL at line 164
%FORT-I-EXT_KEY, Extension to FORTRAN-77: Nonstandard keyword
        [LD', READONLY] in module HANKEL at line 168
%FORT-I-ENDDIAGS, SDBRP$DKA0:[ERA.NONVAX_USAGE]ERASUBS.FOR;1 completed with 4 diag
$ FORTRAN/CHECK=(BOUNDS,OVERFLOW)/STANDARD=ALL ERAMLB
$ FORTRAN/CHECK=(BOUNDS,OVERFLOW)/STANDARD=ALL ERASYS_NONVAX
$!
$ LINK/EXE=ERA_NONVAX ERAMAIN,ERASUBS,ERAMLB,ERASYS_NONVAX
$!
$ DELETE *.FOR;*
%DELETE-I-FILDEL, SDBRP$DKA0:[ERA.NONVAX_USAGE]ERAMAIN.FOR;2 deleted (33 blocks)
%DELETE-I-FILDEL, SDBRP$DKA0:[ERA.NONVAX_USAGE]ERAMAIN.FOR;1 deleted (33 blocks)
%DELETE-I-FILDEL, SDBRP$DKA0:[ERA.NONVAX_USAGE]ERAMLB.FOR;1 deleted (309 blocks)
%DELETE-I-FILDEL, SDBRP$DKA0:[ERA.NONVAX_USAGE]ERASUBS.FOR;1 deleted (546 blocks)
%DELETE-I-FILDEL, SDBRP$DKA0:[ERA.NONVAX_USAGE]ERASYS_NONVAX.FOR;1 deleted (3 bloc
%DELETE-I-TOTAL, 5 files deleted (924 blocks)
$ DELETE *.OBJ;*
%DELETE-I-FILDEL, SDBRP$DKA0:[ERA.NONVAX_USAGE]ERAMAIN.OBJ;1 deleted (15 blocks)
%DELETE-I-FILDEL, SDBRP$DKA0:[ERA.NONVAX_USAGE]ERAMLB.OBJ;1 deleted (48 blocks)
%DELETE-I-FILDEL, SDBRP$DKA0:[ERA.NONVAX_USAGE]ERASUBS.OBJ;1 deleted (303 blocks)
%DELETE-I-FILDEL, SDBRP$DKA0:[ERA.NONVAX_USAGE]ERASYS_NONVAX.OBJ;1 deleted (3 bloc
%DELETE-I-TOTAL, 4 files deleted (369 blocks)
$!
$ COPY ERA$MMST_NAS:T1NAMES_INIT_20_50.DAT  70_INPUT_FILE.DAT
$ COPY ERA$HELP:ERROR_MESSAGES.LIS          75_INPUT_FILE.DAT
$ COPY ERA$MMST_NAS:NAMELIST_INIT_20_50.DAT 77_INPUT_FILE.DAT
$ COPY ERA$MMST_NAS:JOBDESC_INIT_20_50.DAT  90_INPUT_FILE.DAT
$!
$ ASSIGN/USER 70_INPUT_FILE.DAT FOR070
$ ASSIGN/USER 75_INPUT_FILE.DAT FOR075
$ ASSIGN/USER 77_INPUT_FILE.DAT FOR077
$ ASSIGN/USER 90_INPUT_FILE.DAT FOR090
$!
```

```
$ ASSIGN/USER 50_OUTPUT_FILE.LIS FOR050
$ ASSIGN/USER 51_OUTPUT_FILE.LIS FOR051
$ ASSIGN/USER 55_OUTPUT_FILE.LIS FOR055
$ ASSIGN/USER 79_OUTPUT_FILE.LIS FOR079
$ ASSIGN/USER 85_OUTPUT_FILE.LIS FOR085
$ ASSIGN/USER 88_OUTPUT_FILE.LIS FOR088
$!
$ RUN ERA_NONVAX
$!
$ PURGE
%PURGE-I-FILPURG, SDBRP$DKA0:[ERA.NONVAX_USAGE]90_INPUT_FILE.DAT;1 deleted (3 bloc
%PURGE-I-FILPURG, SDBRP$DKA0:[ERA.NONVAX_USAGE]ERA_NONVAX.EXE;1 deleted (255 block
%PURGE-I-TOTAL, 2 files deleted (258 blocks)
$!
$ DIRECTORY/SIZE *_OUTPUT_FILE.*

Directory SDBRP$DKA0:[ERA.NONVAX_USAGE]

50_OUTPUT_FILE.LIS;1
                          69
51_OUTPUT_FILE.LIS;1
                         660
55_OUTPUT_FILE.LIS;1
                          76
79_OUTPUT_FILE.LIS;1
                         271
85_OUTPUT_FILE.LIS;1
                           8
88_OUTPUT_FILE.LIS;1
                         126

Total of 6 files, 1210 blocks.
$!
$ SET NOVERIFY
```

APPENDIX H - SOFTWARE MODIFICATIONS LOG (MODLOG.LIS)

1. ERAG1. 891111.

Time- and freq.-domain data can now be plotted together using multiple plots per page; i.e., plot type #3 now permits multiple plots per page. (Sample available: [ERA.GO]G1_BOTH_DEMO)

---

2. ERA. 891111.

I88NEV = 0 permits unlimited number of mode shapes to be written to TAPE88 .UNV file (named jobname.PT1). This unlimited-length file can be handled by TDAS. MODAL-PLUS is limited to 40 mode shapes per file (default value for I88NEV).

---

3. ERA. 891111.

Load case number written to TAPE88 is now equal to 1000 * ICASE + IEVNUM, rather than simply ICASE. (Post-processors can decompose it back into ICASE and IEVNUM.)

---

4. ERAP25. 891111.

Modified to decompose Load Case Number into ICASE & IEVNUM.
LCASE = 1000 * ICASE + IEVNUM.

---

5. ERA. 891112.

Print out COMPUTER NODENAME AND TYPE at end of TAPE50.

---

6. ERA. 891116.

Rotational coordinate codes (+/-4,+/-5,+/-6) now permitted. These directions are referred to as U,V,W (will be changed to RX,RY,RZ later).

---

7. ERAG5. 891117.

Fixed bug with x-axis minor tic marks (were not being plotted).

---

8. ERAP0B. 891117.

NEW PROGRAM. Prints a directory of a Type 58 (FRF or time history) Universal File.

---

9. GDPOSTSCR (DIGLIB). 891118.

Unique file name now used for each postscript file, to avoid possible conflicts when 2 or more graphics programs as running simultaneously.

---

10. ERAP25. 891118.

Now prints FD rather than FN with full correlation matrix. Also prints FD for complex modes and FN for normal modes when reading in files.

---

11. ERAP1. 891118.

Skip looking for coordinate-code file if TAPE1 filename does not begin with 'T1'.

---

12. ERA. 891118.

Corrected WD written to TAPE79 for real eigenvalues located at the Nyquist frequency. Accidently was writing these to TAPE79 as WD = 0.0 Hz.

---

13. ERAP10. 891118.

In conjunction with Item #12, corrected reconstruction of real eigenvalues with WD = Nyquist Frequency. Was mistakenly using WD = 0 Hz for all real eigenvalues.

---

14. ERAG1. 891119.

Multiple record nos. per plot now printed correctly at top of plot.

---

15. ERA_MASTER.COM. 891119.

Renamed T1NAMES_ERA.TMP & NODENAME_ERA.TMP To T1NAMES_ERA_'JOBNAME'.TMP &

NODENAME_ERA_'JOBNAME'.TMP to avoid possible conflict when more than one job is running simultaneously.

---

16. ERAG1. 891121.

Time window to plot is now specified in terms of TSTART and TEND, rather than the number of points to plot. This allows flexibility to begin plot at times other than t=0.

---

17. ERAG15. 891128.

Start y-axis at zero if requested first case no. = 1.

---

18. ERAG15. 891128.

Automatic extension of x-axis (Freq.) to other-than-requested values overrode.

---

19. ERA_MASTER.COM. 891128.

Increased max. number of TAPE88 files from 10 to 30.

---

20. ERAP25. 891129.

MXMODES defined for each file separately, rather than using same limit for both.

---

21. ERAP25. 891130.

Brief file description can now be printed next to the file names, e.g., 'NASTRAN ANALYSIS' or 'ERA RESULTS'

---

22. ERAP4. 891201.

NEW PROGRAM. Sorts TAPE1 data by Coordinate Codes (e.g., in order of increasing location numbers)

---

23. ERAG15. 891204.

Weighted and Unweighted Modal Phase Collinearity and Avg. EMAC can now be plotted in the righthand plot.

---

24. ERAP0B. 891204.

Now prints out No. of Data Pts. for each record.

---

25. ERAP2. 891204.

Changed printout to be the same as for ERAP0B (i.e., Ref. CC, Resp. CC, and No. of Data Pts. per record).

---

26. ERAG15. 891204.

Y-axis prints correct name and values automatically (rather than just 'ICASE') based on the value for IOPT. Can also still select 'CASE NO.' for y-aixs label if desired.

---

27. ERAP2. 891206.

Modified to read to end of file if data for each reference is not stored contiguously in the .UNV file.

---

28. ERAP2. 891206.

Can now select specific sequence no. (or -1 for all) to read from .UNV file.

---

29. ERAP2. 891211.

Range of response locations numbers now requested.

---

30. ERAP20. 891211.

NST now printed at end of run.

---

31. ERAP88. 891211.

Added READONLY parameter to TAPE1 & TAPE2 OPEN statements.

---

32. ERAG2. 891213.

NEW PROGRAM to plot peaks in spectra using simple sliding window, peak-picking technique. (The program previously named ERAG2 was renamed as ERAG2B; ERAG2B was renamed as ERAG2_3D and removed as an active ERA pre-processor program because it needs more work.)

---

33. ERAP0B. 891214.

Now prints out Sequence No. also.

---

34. ERAP2. 891215.

Modified printout to be the same as with ERAP0B and ERAP20.

---

35. ERAP79. 891215.

REMOVED THIS PROGRAM FROM LIST OF ACTIVE PROGRAMS. (ERAP79 converts Modal-Plus ADC Throughput files to MATRIXx format.)

---

36. ERA. 900104.

Eliminated fatal error which occurred in subroutine OUTMAC (ATAN2(0,0)) if all data for a measurement was exactly zero. The error occurred when computing OMAC in this situation. Modified to write a warning message to TAPE50, and to set the corresponding OMAC to 0.0

---

37. ERA. 900111.

On TAPE50, changed printer plot of Modal Strength Ratio (MSR) from logarithmic to linear format. Also reduced no. of digits printed to the right of decimal pt. (in MSR) from 3 to 1.

---

38. ERAG15. 900116.

Can now plot Modal Strength Ratio in right-hand plot.

---

39. ERA. 900117.

Changed default value for parameter I88NEV from 40 to 0 (0=unlimited number of modes written to TAPE88).

---

40. ERA. 900117.

New user parameter MSSCAL, to select mode shape scaling convention for data written to TAPE88.

---

41. ERA_MASTER.COM 900118.

Fixed bug that caused fatal error when NIC was >= 10. Everything will work now up to NIC = 20.

---

42. ERA.COM 900118.

Fixed bug in writing EMAC values to TAPE51) when NIC was > 7 (output statement overflow. Temp. patch to print out only the first 7 I.C.'s.

---

43. ERAG25. 900125.

NEW PROGRAM written by Chris Noll. Plots MAC or Orthogonality results generated with ERAP25. Uses darkened squares to highhlight values above selected threshold.

---

44. ERAG15. 900126.

Modified to plot "Time Shift, Sec." rather than "NSKIP" for IOPT=2.

---

45. ERAP4. 900127.

Added new option to sort by ascending location nos., with interleaved x,y,z data.

---

46. ERAMLB. 900209.

Modified REQR to sort real eigenvalues in descending rather than ascending order, causing s-plane eigenvalues at DC to be listed prior to those at the

Nyquist frequency.

---

47. ERA. 900223.

Modified the 48-character I.D. line written to TAPE88 to assume that jobname appears at the beginning of line 5 of the user comments (20 chars. max.), followed by a colon.

---

48. ERAG15. 900225.

Fixed problem with inconsistent y-axis minor tic marks.

---

49. ERAG2. 900227.

Fixed bug when NTIM > NTIMMX/2. Accidently used DATA() rather than T1DATA() in TAPE1 read command.

---

50. ERA. 900302.

Skipped calculation of IMAC and OMAC (obsolete, replaced by EMAC). IMAC and OMAC can be still be calculated and printed on TAPE85, if desired, by setting user parameter IOMAC=1.

---

51. ERAG15. 900304.

Added capability to use new "Consistent Mode Indicator--CMI" (==EMAC*MPC-W) as either or both the ht. of lines in freq. plot or as the parameter plotted in second plot.

---

52. ERA. 900316.

Added capability to stop program gracefully for various diagnostic reasons, using ISTOPS() user parameter.

Implemented ISTOPS(1)=1 to write HRS0 to TAPE79, then stop.

---

53. ERA. 900323.

Changed user parameter T88MAC to T88CMI to use CMI rather than EMAC for cutoff criterion to save modes to TAPE88. Also modified header ID in

each TAPE88 record to contain CMI, rather than EMAC.

---

54. ERAP89. 900324.

New program.
UTILITY PROGRAM TO SUBTRACT CONSECUTIVE TAPE1 RECORDS FROM
FROM ONE ANOTHER AND WRITE DIFFERENCE OUT TO ANOTHER FILE.
CAN BE USED TO EXAMINE DIFFERNCE BETWEEN DATA AND RECONSTRUCTION.

---

55. ERA. 900329.

Added ROTDEG info. to TAPE50 printout. ROTDEG is the phase rotation, in degrees, between each mode shape (for each I.C.) in physical units and +/- 90 degrees. The "average" phase for the mode is derived using the normalized mode shape result printed on TAPE50.

---

56. ERAP21. 900510.

New program.
Artificially increase the sampling frequency of TAPE1 data by
FFT/zero padding/IFFT.

---

57. ERA. 900516.

ZETA & ZETA2 are now printed on header line 2 on TAPE88. Also, mode shape scaling convention printed on header line 3.

---

58. ERAP10. 900802.

Reconstruction can now use either std. damping factors, derived from the identified eigenvalues, or zeta2, derived from identified eigenvector components at the beginning vs. end of the data analysis window.

---

59. ERAG15. 900806.

Fixed bug with selecting log axis. Log axis appeared with parameters other than amplitude if it was selected for amplitude.

---

60. ERAG15. 900806.

Added option to plot phase information.

---

61. ERA.COM 900809.

Changed file type of all temporary files used during the ERA run to .TMP so they can be more easily deleted if the job is aborted.

---

62. ERA.COM 900809.

Cleaned up the way in which the calculation of discrete [A,B,C,D] matrices is requested. Now enabled by simply specifying MODELD = 1 (MODELD = "discrete model." Matrices written to TAPE79 in MATRIXX format. If MODELD = 1, the remainder of the code is skipped after the [A,B,C,D] matrices are written to TAPE79. Can also specify MODELD = 2, which is the same as MODELD = 1 except that the remainder of the software after TAPE79 is written is not skipped.

Note that when MODELD = 1 or 2, the first data pt. in each time history is placed into DDERA() (discrete D matrix), and then ERA skips over the first data pt. in the remaining calculations.

The MATRIXX matrix names are ADERA, BDERA, CDERA, and DDERA.

The default value for MODELD is 0, used for std. modal identification runs.

---

63. SUERA.COM 900907.

Users on other computers can now access ERA remotely over DECNET by using @[ERA]SUERA REMOTE, rather than simply @[ERA]SUERA.

---

64. ERA 900910.

Minor bug corrected: The default value of IRUNAV has been 1 (?). Changed to 0.

---

65. ERA 900911.

Eliminated occasional output conversion error message when writing TAPE50 (in subroutine PPLMSR). The problem was ZETA2 which occasionally exceeded the F6.3 field. Fixed by printing 99.999 if ZETA2 >= 100.000 and -9.999 if ZETA2 <= -10.000.

---

66. ERA 900911.

Fixed minor bug: No modes were written to TAPE88 when ITAPE(50)=0; all modes were thought to have a CMI = 0 because MPC-W was not being saved for further use when ITAPE(50)=0.

---

67. ERAP2 900913.

Modified ERAP2 to allow user to enter a large number for NTIM to use all available data. (The user generally didn't know what no. to enter for NTIM when running ERAP2 from a GO file.)

---

68. ERAP2 900913.

Fixed bug that occurred when reading TDAS Type 58 file and the last data line contained only 1 spectral line. The program was trying to read this last data line as the "-1" trailer because of an incorrect index under these conditions.

---

69. ERAG5 900913.

Fixed bug that aborted the program prematurely (saying that FOR051 could not be found). The error statement number appearing in the initial OPEN(77... and READ(77... statements should have pointed to the PRINT 10 statement, rather than to statement 234.

---

70. ERAG5 900917.

Added new option to write sorted measurement nos. (i.e., record nos.) to FOR090 if sorted option is selected. (Can be used to select KEYDTA based on largest identified mode-shape components.)

---

71. ALL GRPAHICS PROGRAMS 900917.

Removed the question "Automatic hard copies?" appearing whenever a TEK graphics device is selected. TEK hard copy units are only seldom used now. For users with such devices, subroutine SGDRSP in file RSPGGRA.FOR can be modified to turn this capability back on, followed by recompiling everything by @ERA$COMS:RECOMPILE_ALL_GRAPHICS.

---

72. ERAG15 900918.

On postscript hard copies, vertical dashes on the freq. plot did not appear

when the corresponding accuracy indicators were less than approx. 5%. This problem was fixed by making the minimum vertical dash height plotted to be 5% of the maximum.

---

73. ERAG7 900918.

Can now select Case No. of data to extract from TAPE85.

---

74. ERA 900918.

Fixed bug with Warning Message No. 9 accidently staying on at higher case numbers in IOPT=1 jobs.

---

75. ERAP26 900920.

Mode shapes were being written out using 6E13.5 format rather than 1P6E13.5. Using only E13.5 dropped 1 digit of precision. Format statement changed in all P26 programs.

---

76. ERA 900921.

When MSSCAL = 1 or -1 (normalized mode shapes), the data written to TAPE88 were not adjusted for the polarity of the response sensors. Problem corrected.

---

77. ERATST 900925.

ERATST.FOR was renamed MIMO.FOR, to be named consistently with SISO.

---

78. ERA 901025.

Added the option to all graphics programs to modify default plot parameters when printing Postscript files. Currently, x and y magnifications and line width can be modified. A new question asking "Modify default plot parameters?" occurs when a Postscript printer is selected (8 or 10 in graphics device list).

---

79. All graphics programs 901026.

Optional fonts were not being initialized. Bug fixed.

---

80. ERAP3 and ERAP3B (New Program) 901031.

ERAP3 was renamed ERAP3B. ERAP3 was written to convert ERA Tape1 files to FRFs in SDRC Universal file format. (ERAP3B converts Tape1 files to time-history Universal file format.) This new naming convention is consistent with that used for ERAP2 and ERAP2B.

---

81. ERAP1 and ERAP1B. New Programs. 901031.

New programs to convert SDRC ADF files (either .ATI or .AFU) to ERA Tape1 and MATLAB format, respectively. Written by Ken Graham, a co-op from the University of Alabama. (These programs have not yet been used by anyone except Ken. "Use at your own risk" -- for now. RSP)

These files were originally named ADFtoERA and ADFtoMAT.

Documentation is available in files ERA$HELP:ERAP1.HLP and ERAP1B.HLP.

---

82. All Graphics Programs. 910122.

Added drivers to generate file (PLOT.HPGL) in HPGL format, using either tall or wide size. Also rearranged list of plot device numbers to place the 2 HP and 2 Postscript selections consecutively.

---

83. ERAG15. 910128.

Last case plotted is now printed out when an unexpected EOF is encountered.

---

84. ERASUBS. 910128.

Added ZETAP,ZETAP2,EMAC,MPC-W,MPC-U data to TAPE88 header.

---

85. ERASUBS. 910129

Added to subroutine WTPE85:

> PARAMETER 'ICAS85' ADDED 1-29-91 TO ALLOW THE CASE NOS. WRITTEN TO TAPE85 TO BEGIN AT 'ICAS85' RATHER THAN 1, TO ALLOW MULTIPLE TAPE85 FILES (FOR DIFFERENT PARAMETER RANGES) TO BE APPENDED TOGETHER AS IF THEY WERE RUN IN THE SAME JOB. USEFUL WHEN QUEUE TIME LIMITS RESTRICT THE NUMBER OF CASES THAT CAN BE PERFORMED WITHIN ANY ONE ANALYSIS.

---

86. ERASUBS. 910129

Fixed bug: Warning Message 10 was incorrectly being issued for ICASE > 1 when IOPT=1.

---

87. ERASUBS. 910130

Write out execution time statistics to TAPE50 at the end of every job, even if ITAPE(50).NE.1.

---

88. ERAG5. 910131

Eigenvalues can now be specified by either a list of nos. or by the first and last values of a range.

---

89. ERAP5. 910204

NEW PROGRAM. Extract various records from a Tape1 data file.

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90. ERAG15. 910205

Added ZETA2 to the list of parameters which can be plotted in plots 2+.

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91. ERASUBS. 910205

Added calculation of the DLR Phase Resonance Criterion, based on the identified, normalized (phase-rotated) mode shapes. Compute both Weighted and Unweighted values, analogous to MPC. Output PRC-W and PRC-U on Tape85, replacing obsolete IMAC and OMAC.

---

92. ERAP25. 910207

Fixed minor bug in ERAP25: description of File 2 at top of printout of full correlation matrix was not being printed.

---

93. ERAG25. 910207

Fixed minor bug in ERAG25: squares above selected tolerance were not being shaded. Discovered that READR rather than READI call was made when 'tol' was read in.

---

94. ERASUBS. 910306

Removed several minor diagostic errors that were encountered during compilation. There are now 4: 2 for NAMELIST and 2 for READONLY.

---

95. ERASUBS. 910306

Changed the name of parameter IOPT to LOOPOP. This parameter selects various looping options. LOOPOP is a more appropriate name.

---

96. ERAP10. 910306

Changed the name of parameter IOPT to LOOPOP for reading Tape79 file).

---

97. ERASUBS. 910311

Added No. of Input EMACs >= 80 and No. of Output EMACs >= 80 to Tape50. Also print all Input and Output Emacs on Tape50 in last section (sorted by frequency).

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98. ERAP25. 910315

Added option to use only description for axes labels (when results are plotted with ERAG25).

---

99. ERAG25. 910315

Added option to skip writing case nos. and eigenvalue nos. on plot.

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100. ERAG1 & ERAG15. 910315

Added option to interactively enter the maximum number of major plot divs.

---

101. ERASUBS 910322

MAJOR MOD.: Changed the definition of Avg. EMAC to be computed as a weighted average. The weights are the corresponding mode-shape and modal-participation factors, respectively, for the output and input EMACs.

---

102. ERASUBS 910409

Changed the second field of Tape50 from 'Sorted by MSR' to 'Sorted by PRC'.

---

103. ERAG5B. 910430

NEW PROGRAM. ERAG5B is the old program ERAG5, which plots mode shapes from TAPE51. THE NEW ERAG5 PLOTS MODE SHAPES FROM TYPE 55 UNIVERSAL FILES (E.G., TAPE88). (Plotting from Tape88 is expected to make TAPE51 files obsolete, and so this new program is named ERAG5, rather than ERAG5B.)

---

104. ERAP26_5 (P26_MPC_CALC.FOR). 910502

Compute Phase Resonance Criterion (PRC) of modes in a Type 55 Universal File, in addition to MPC.

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105. SUERA.COM 910711

Renamed logical name ERA$GO to ERA$USER_GO, which now points to the current default directory rather than to a directory named [.GO] under the user's login directory. I.e., users now should put all GO .COM files in the 'project' directory they are working in, rather than all in the [.GO] directory. The [.GO] directory is no longer needed and can be deleted.

New logical name ERA$GO now points to ERA$DISK:[ERA.GO], the directory containing master copies of all GO files. Users can obtain sample copies of current go files by copying them from this directory.

---

106. [ERA.NONVAX_USAGE] 910725

New directory for demonstrating how ERA can be used on other computers; i.e., without the USER INPUT FILE and ERA.COM developed to simplify use on VAX computers.

Command procedure DEMO.COM in this directory runs the ERA$PLT:PLT1A demo problem without using a USER INPUT FILE or ERA.COM.

---

107. ERAG3. 910731

Added new option to plot singular values vs. either "assumed no. of modes" or vs. "singular value no." Assumed No. of Modes = (Singular Value No.)/2.

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108. ERA. 910822

Added user parameter IPREMC to print out details of EMAC calculation on TAPE50, if IPREMC = 1.

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109. ERAG4. 910828

NEW PROGRAM. Plot avg. power spectrum or mode indicator fct. using Tape1 data.

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110. ERA. 910911

Created new output file, TAPE55, to contain individual EMAC results. These data are used for selecting KEYDTA measurements for emhpasized-data analyses.

---

111. ERAG25. 911011

Added option to draw vertical line at start of each new case no. in file #2.

---

112. ERAP2D. 911030

NEW PROGRAM. Generates IRFs in Tape1 format from DLR .RSP file using "slow" Fourier transform, permitting unequally spaced freq. data to be used. Can be used with either up or down sweeps.

---

113. ERAG15. 911105

Fixed bug with letter size in plots 2+ when plotting a subset of case nos. Letters were being plotted too small (size was calculated based on the total number of cases in the Tape85 file, not the total no. of plotted cases.

---

114. ERAG1. 911107

Added option to plot time histories using log scale.

---

115. All Graphics Programs. 920406

When PostScript output was requested with multiple plots, the question "Use Default Plot Parameters?" was being asked at the beginning of every plot. Modified so that the question is only asked once when multiple plots are generated.

---

116. ERAP26 920407

IMPORTANT BUG DISCOVERED. This program always included all 3 dofs in the MAC and x-ortho calculations. The results are correct for test-test (or analysis-analysis) correlations since those dofs not included in the test normally have all 0.0's IN
BOTH FILES to be correlated, which doesn't affect the result. However, when test and analysis are correlated, it is entirely possible that the analysis file has info. where the test file does not. THESE DOFS SHOULD NOT BE INCLUDED IN THE CALCULATION. The format of the "location trace" file has been modifed to include a third parameter on each line. This parameter declares which dofs are to be used in the correlation calculation for the corresponding location nunber. The software uses the 100's digit as yes (1) or no (0) for the x dof, the 10's digit as yes (1) or no (0) for the y dof, and the 1's digit as yes (1) or no (0) for t he z dof. E.g., 101 means include only the x and z data in the correlation calculation.

---

117. ERAG1 920414

Added option to plot spectrum magnitude using either linear or log scale.

---

118. ERAG4 920414

Added option to save computed functions in Tape1 format (can then be plotted with ERAG1, or ERAG7).

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119. ERAG1 & ERAG7. 920415

Added option to skip spectrum phase plot. Useful for plotting Mode Indicator Function generated by ERAG4.

---

120. ERAP30. 920429

NEW PROGRAM. Calculates analytical FRFs using (type 55) .UNV mode shape file.

IRFs computed with inverse Fourier transform then written out to a TAPE1 data file.

---

121. ERASUBS. 920430

Changed the default value of MXORDR from MIN(NRH,NCH)/2 to 0.75 * MIN(NRH,NCH).

---

122. ERASUBS. 920412

Modified print format of Tape55 so that KEYDTA output info. fits in 72 character wide field.

---

123. ERAG15. 920528

Overrode DIGLIB's extension of the x-axis close to major tic marks, otherwise some portions of the frequency plot may appear blank when, in fact, modes actually occur in that frequency interval.

---

124. All Graphics Programs. 920610

Fixed a problem with DIGLIB using poor axis labels occassionally, especially when a narrow parameter range was plotted.

---

125. ERASUBS. 920611

New user parameter: MSTO50. If MSTO50 ("Mode shapes to Tape50") = 1, mode shapes in Tape51 format are also printed on Tape50 (numbers only; not printer plot).

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126. ERASUBS. 921511

Fixed potential divide by 0 error in subroutine INMAC (variable CDATA).

---

127. MIMO. 921511

Implemented default values for all parameters.

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128. ERASUBS. 920618

New user parameter: MSPP50. If MSPP50 = 1 (the default), write mode shape printer plot on Tape50 (if MSTO50=1).

---

129. ERASUBS. 920618

Removed the EMAC numbers printed on Tape51 between the Amplitude and Phase results on the printer plot. This information (output EMACs for each measurement) are available on Tape55.

---

130. ERAG15. 920622

Fixed small bug in ERAG15: could plot dotted vertical lines in Plots 1 & 2, but not in Plots 3 & 4.

---

131. ERAP79. 920630

NEW PROGRAM. Converts Tape79 file (MATRIXx format) to MATLAB .MAT file.

---

132. ERAP76A. 920630

NEW PROGRAM. Converts Tape1 data file(s) to MATLAB .MAT file format. ALSO, renamed old ERAP75 as ERAP75A, and old ERAP76 as ERAP75B.

---

133. ERAG6. NEW PROGRAM. 920715

Computes and plots cross-correlation coefficients of Tape1 data records. Also, sorts results according to no. of times each record correlates above a specified threshold (default = 0.9) with other records.

---

134. All Graphics Programs. 920715

New capability developed to select specific axis tic labels from within FORTRAN programs. Modified ERAG1, ERAG7, ERAG5, ERAG5B to label y-axis in phase plots in increments of 90 deg. from -180 to +180.

---

135. ERAG15. 920716

New hidden option: NFWNDS =2,
CAUSES PROGRAM TO ASK FOR 2 FREQUENCY WINDOWS; I.E.,
2 FREQUENCY INTERVALS OVER WHICH EIGENVALUES WILL BE RETAINED
FOR PLOTTING. IF THE 2 SELECTED FREQUENCY RANGES ARE FREQF1-FREQL1
AND FREQF2-FREQL2, THE FREQ. PLOT WILL EXTEND FROM FREQF1 TO FREQL2
(ASSUMING FREQF1 < FREQF2); HOWEVER, ONLY THOSE MODES WITH
FREQUENCIES BETWEEN FREQF1-FREQL1 OR FREQF2-FREQL2 ARE DISPLAYED.

This option was requested by Cheri Tanner.

---

136. ERAP85. 920727

NEW PROGRAM. Extracts response nos. from a TC file for building list for P26_6.

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137. ERAG10. 920727

NEW PROGRAM. Read Mode Shape .UNV file and plot freq. vs. mode no.

---

138. ERASUBS 920728

Fixed potential subscript out of range error occuring when variable NIAIMX was zero. Renamed variable NIAIMX to NIMX88 and added new NIAIMX which is always nonzero.

---

139. ERAG1 920730

Modified y-axis labels on phase plot to be -180,0,180 or -180,180 rather than always -180,-90,0,90,180 when plots smaller than full page are generated.

---

140. ERAP98. 920807

NEW PROGRAM.

Utility program to multiply tape1 data records by a specified constant.

---

141. ERAP76B. 920817

NEW PROGRAM.

Convert MATLAB .MAT file variable(s) to Tape1 format.

*** NOTE: The .mat file must have been written on a VAX ***

---

142. ERASUBS. 920901

Added a fatal error if NSKIP>0 when MODELD>0 is specified.

---

143. ERASUBS. 920901

NEW PARAMETER: MODELC.

If MODELC=1 or 2, set DC_MODAL array (written to Tape79) = DATA(1)/SF and then zero out DATA(1) before proceeding with the analysis. This option is used to generate a continuous-time [a,b,c,d] model for MATLAB. If MODELC=1, stop after matrices are written on Tape79; if MODELC=2, don't stop. Default value of MODELC=0, which means don't modify DATA(1) and don't worry about dc_modal (traditional modal id).

---

144. ERAP76C. 920908

NEW PROGRAM.

CONVERTS MATLAB ASCII .MAT FILE TO ERA TAPE1 FORMAT. 1 ARRAY ONLY, ASSUMED TO BE A TIME HISTORY !!!

---

145. ERAP25. 920910

Added new option to compute amplitude-weighted MAC. This capability appears to be very useful for differentiating global from local modes on problems like Space Station Freedom where most measurements will be on the truss. (Many "appendage modes" look very similar to the important, global truss modes when viewed only on the truss; however, their response amplitude will generally be mush smaller than that of the global mode. The amplitude-weighted MAC is computed my multiplying mAC by the "Modal Scale Factor" (normalized for max. MSF = 1).

---

146. ERAP30. 920917

Added option to save out individual modal components to the Tape1 file.

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147. ERAP10B. 921013

NEW PROGRAM.

SIMULATION OF DISCRETE-TIME LINEAR SYSTEMS WITH
ARBITRARY INPUTS

SOLVES: X(N+1) = AX(N) + BU(N)
Y(N) = CX(N) + DU(N)

Uses [ADMODAL,BDMODAL,CDMODAL,DDMODAL] from Tape79.

---

148. ERASUBS. 921021

Added new analysis parameter: NOAD79.

If NOAD79 =1 (and MODELD = 1 or 2, don't
write [ad,bd,cd,dd] to Tape79. (Write [z_evalues,bd_modal,cd_modal,dd_modal].)
This option was developed for applications when program ERAP10B is used to
perform discrete-time simulations. ERAP10B uses
[z_evalues,bd_modal,cd_modal,dd_modal] and the Tape79 was becoming unacceptably
large in looping analyses in [ad,bd,cd,dd] was also written to Tape79.

---

149. ERAP70. 921023

NEW PROGRAM. (Written by Zoran Martinovoc)

Converts time histories on NASTRAN PUNCH file to Tape1 format.

---

150. ERAP80. 921026

NEW PROGRAM.

Extracts a specified case no. from a Tape79 file.

---

151. ERASUBS. 921028

Modified code to run much quicker in the situation when Tape88 is written and
the max. response location no. is very large (e.g. 6 digits). [Avoided the
construction of an excessively large Tape89 file in this situation.]

---

152. ERAG15. 921029

When using hidden option MARKFD=1 to draw inverted triangles at the top of the plot to designate NASTRAN-predicted freqs. (and assigned damping values), if mode no. (the first col. of data on the input file) is preceded by a minus sign, the corresponding inverted triangle is darkened. This option was added so that important modes can be highlighted.

---

153. ERAG4. 921029

Added option to select scaling method for time to freq. fft:
1. Multiply by dt (to convert irf to frf)
2. Divide by N (to obtain correct sine wave ampl. independent of record length)

---

154. ERAP27. 921102

NEW PROGRAM.
Utility program which reads a .loc file (used by ERAP25) and prints out the x, y, z, and total number of dofs specified. Also, these dofs can be compared with the contents of a coordinate-code file.

---

155. ERAG1. 921102

Corrected bug in DIGLIB subroutine LAXIS which incorrectly erased the screen prior to plotting freq.-domain magnitude plot with log y axis, when default axis labels where modified (the last question asked by ERAG1).

---

156. ERASUBS. 921103

Changed default value of parameter MSSCAL (mode shape scaling) from 1 to 2 (residues) so that new option to compute amplitude-weighted MAC in ERAP25 will function properly with default Tape88 file.

---

157. ERAG7. 921103

Finalized option to normalize mode shapes in same manner as printed to Tape51: amplitude normalized 0-100 and phase rotated to best fit near +/- 90 degrees.

---

158. ERAP25. 921104

Added option to print out either damped or undamped natural frequencies.

---

159. ERAG50. 921117

NEW PROGRAM. Plots mode shapes (wireframe model) using data from Tape88 (.UNV files).

---

160. ERAG5. 921124

Added damping information at the top of the plot.

---

161. ERAP11. 921125

Updated names of variables on Tape79 file. (Changed to lower case and updated some names.)

---

162. ERAP125. 921209

NEW PROGRAM.
Tabulate identified modes for a simulated experiment. Compare identification results from a Tape88 file against a reference NASTRAN mode shape read from a .UNV file. Determine which modes satisfy the following 4 criteria simultaneously: CMI >= 80%, frequency error <= 1%, damping error <= 20%, MAC >= 90%.

---

163. ERASUBS. 930125

FIXED BUG. Stopped printing of singular value printer plot on Tape50 when ITAPE(50)=1.

---

164. ERAP20. 930129

Added new option to compute IRF using only the imaginary part of the FRF. The method is described in the following reference: Keqin, X., "Using the Imaginary-Part of FRF For Modal Identification and IRF Estimation," Proc. of the 10th IMAC, Feb. 1992, pp. 1431-1437.

---

165. ERAP21. 930310

NEW PROGRAM. (Old ERAP21 was renamed ERAP24.)
Digital filtering of Tape1 data records using a FIR Low/Band Pass Filter. This program was obtained from Dr. Hyoung-Man Kim at McDonnell-Douglas.

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166. ERAP26, Option 10. 930311

NEW PROGRAM. Lists all dataset numbers and corresponding line numbers in a .UNV file.

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167. ERAP26, Option 11. 930316

NEW PROGRAM. Multiply or divide a Mode Shape (Type 55) .UNV file by WN or WN**2.

---

168. ERAG50. 930322

Fixed bug discovered that gave wrong view when z axis was aligned vertically on x-y display.

---

169. ERAG50. 930322

Added option to orient structure's -x, -y, or -z axes with +y axis of display. (Previously, only +x, +y, and +z could be aligned with +y of display.)

---

170. ERAP26, Option 1 (P26_MODE_EXTRACT.FOR). 930324

Added option to extract modes from a .UNV file by Case No. only.

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171. ERAG50. 930325

Changed definition of triade leg length from e.u. to cm.

---

172. ERAG5. 930325

Added new option to normalize plotted mode shape to a user-specified measurement nunber. This measurement no. is assigned a magnitude of 100% and phase of 90 deg.

---

173. ERAG50. 930326

Added option to number only those points provided in file NUM_POINTS.DAT.

---

174. ERAP76C. 930329

Added option to permit the input MATLAB ASCII file to have the time histories stored in either the rows or columns.

---

175. ERAP5. 930329

Added option to write out every data point, or every 2nd data pt., etc. (called a data parsing factor).

---

176. ERAG1. 930330

Fixed bug in plotting the last point when time-domain plot only requested, and NTIM is an odd number.

---

177. ERASUBS. 930331

Fixed bug that occurred when Tape88 was activated (ITAPES=88) and MIDOPT.NE.0. (Nothing was written onto Tape88).

---

178. ERAP6. 930331

NEW PROGRAM. Change Ref. location no. and/or direction in a coordinate code file.

---

179. ERAP125. 930331

Modified to permit a range of NASTRAN modes to be specified, rather than just one.

---

180. ERAP26, Option 6 (P26_NODE_EXTRACT). 930401

Modified to check that each given grid pt. no. occurs only once in the input .UNV file. If a given grid pt. no. occurs more than once in the input file, a warning message is issued. The first occurrence of the grid pt. no. is written out.

---

181. ERASUBS. 930401

MAJOR NEW FEATURE: FIR filtering capability (same as available in ERAP21) added to ERA subroutine. Activated by specifying lower and upper frequencies of bandpass FIR filter, FR1FIR and FR2FIR (both must be specified). Order of filter specified by parameter IORFIR. Default value of IORFIR = 50. This subroutine was obtained from Dr. Hyoung-Man Kim at McDonnell-Douglas.

---

182. ERASUBS. 930402

Added parameters FR1FIR & FR2FIR to Tape85 output (replacing parameters FBWLOW & FBWHI).

---

183. ERAG15. 930405

Modified to allow selection of up to 6 plots per page (rather than 4).

---

184. ERAG15. 930405

MAJOR NEW FEATURE: Added option to compute Modal Assurance Criterion (MAC) with a specified NASTRAN mode, if Tape88 file is available.

---

185. ERAG15. 930406

Increased max. no. of plots per page from 6 to 8.

---

186. ERAG5. 930408

Added option to skip phase plot (not needed when plotting NASTRAN mode shapes).

---

187. ERAP26, Option 12. 930409

NEW PROGRAM. Deletes rotations from a mode shape (Type 55) universal file, reducing the file size by half.

---

188. ERAP91. 930409

New program: UTILITY PROGRAM TO APPEND PARTIAL TAPE1 RECORD FROM 2 SEPARATE FILES.

---

189. ERAG5. 930415

Added hidden option (IOVLAY .NE. 0) to overlay multiple curves on the same plot.

---

190. ERASUBS. 930415

Reduced default values of T88CMI and T55CMI to 1.0 from 20.0.

---

191. ERASUBS. 930415

Fixed minor bug. When ITAPE(50)=0, Input Coordinate Code and FBW info. was still being printed.

---

192. ERAG15 & ERAP125. 930415

Fixed bug in computing MAC w/ a NASTRAN mode. Test and analysis info. from .LOC file were accidently reversed. 1st column in .LOC file is TEST grid pt. no. & 2nd column in .LOC file is ANALYSIS grid pt. no.

---

193. ERAG15. 930415

Added print out of maximum CMI and/or MAC w/ NASTRAN mode and the corresponding case no. (to the computer screen) when these parameters are plotted.

---

194. ERASUBS. 930416

Fixed bug that occurred when IPREMC=1 and KEYDTA was used (EOF encountered on LU 22). For each eigenvalue, NST lines were read back from LU 22 and written to LU 55, rather than the correct value of NSTBOT.

---

195. ERAG15. 930420

Added capability to plot MAC in 2 or more plots (rather than in only 1 plot as originally implemented). In this way, MAC with several NASTRAN modes can be examined on one page.

---

196. ERASUBS. 930422

Stopped writing out individual EMAC values to Tape51. This information is now available on Tape55.

---

197. ERA. 930422

SIGNIFICANT MOD. Eliminated the necessity of always having to type the directory name containing the ERA User Input file when submitting an ERA batch job. THE ERA USER INPUT FILE IS NOW ASSUMED TO LIE IN THE CURRENT DEFAULT DIRECTORY. This makes life a lot easier! Everyone has had to include directory names when running batch ERA jobs for years!

---

198. ERAP10B. 930427

Replaced calculation of rms difference between measured and reconstructed responses to average percent error.

---

199. ERAG1. 930428

Added option to plot stairstep time history plot. Use for discrete-time systems (control applications).

---

200. ERAG1. 930513

Fixed bug in choosing automatic scale for y axis of time history when plot started at > t=0 and a large data pt. occurred in the skipped interval (the scaling included the skipped data pts).

---

201. ERAP76C. 930514

Added option to stop after reading in specified no. of rows of the Matlab matrix.

---

202. ERASUBS. 930520

Updated value of NTIM printed on Tape50 to include the IORFIR additional data p
oints
needed when FIR filtering is requested.

---

203. ERAP125. 930616

Added option to skip using CMI or EMAC as one of the criteria for finding identified modes. (I.e., use freq., damping, and MAC only.)

---

204. ERAP125. 930617

Fixed bug. Criterion of freq. error <= 1% was checked on low side, but not on upper side.

---

205. ERAP125. 930617

Added message "Highest MAC thus far for this mode" to make it easy to find result with highest MAC in looping jobs.

---

206. ERAP125. 930623

Modified to select modes based on designated range of case nos., rather than a range of record nos.

---

207. ERAP125. 930701

Modified to permit a user-selected value of CMI or EMAC to be entered as a cutoff criterion, or do not use CMI or EMAC at all.

---

208. ERAP24B. 930706

NEW PROGRAM. Zero-pad Tape1 time histories.

---

209. ERAP85B. 930708

NEW PROGRAM. Extract response nos. and directions from TC file and build a .LOC file (assuming test & analysis dof nos. are the same) for ERAP25.

---

210. ERASUBS. 930709

Added Modal Strength Ratio data to header of Tape88 (Mode Shape Universal File).

---

211. ERAP125. 930709

Added Modal Strength Ratio results to ERAP125 output.

---

212. ALL GRAPHICS PROGRAMS. 930709

Added new subroutine (WRDATE) to RSPGRA.FOR for writing date & time in 0.1 cm letters at lower-right corner of any plot. Add "CALL WRDATE" statement to any program immediately after CALL BGNPLT card.

---

213. ERAP9. 930715

NEW PROGRAM. Builds "Tape79" file for ERAP10B from NASTRAN mode shape .UNV file.

---

214. ERASUBS. 930720

Stopped writing parameter NS (No. of states) to Tape79. Parameter IORDER is the same thing.

---

215. ERAG15. 930728

Fixed bug in hidden option MARKFD=1, which causes inverted triangles to be plotted at the top of the freq. & damping plots at NASTRAN values read from a file. By mistake, all damping values that fell within the selected plot range of the damping plot were drawn. However, only those also corresponding to the modes in the bandwidth of the coresponding freq. plot should be shown.

---

216. ERASUBS. 930728

On Tape50 listing, changed the second section of sorted results from "Sorted by PRC" to "Sorted by MPC-W." The concept of PRC is not used much in the USA.

---

217. ERAG15. 930804

Added new option for specifying an accuracy indicator to be used as a discriminator (only modes meeting the criteria are plotted). New Option 5 permits MPC-W to be used (as Option 2), but also to use a damping contraint. That is, only modes with MPC >= selected value AND damping (%) <= selected value are plotted. The height of the vertical lines in the freq. plot are proportional to MPC-W.

---

218. ERAP92. 930810

NEW PROGRAM. Calculate RMS value of Tape1 data over a specified time window and across multiple records.

---

219. ERAP92. 930811

Modified to permit multiple Tape1 files to be read simultaneously.

---

220. ERAP9. 930811

Fixed bug thta occurred when the same grid pt. no. apeared more than once (with a different direction) in list of requested location numbers. The C and D matrices both had a 0.0 for the second + location nos. that were the same as a previous one in the list.

---

221. ERAP10B. 930811

Added option to specify a range of modes to incluse in the calculation. currently, the specified modes must be in 1 contiguous range. Also, all real eigenvalues, in any, are included. Also, is > 1 mode is specified, the response data can be calculated using each mode individually, or using all specified modes simultaneously.

---

222. DIGLIB (All graphics programs). 930812

Modified subroutine MAPIT to always plot minor tic marks on log axes. Sometimes they were left off (apparently because the tic lines would be too long) even though it seemed like they short be used.

---

223. ERAP92. 930816

Added calculation of std. deviation in addition to rms and peak values.

---

224. ERAP25. 930830

Fixed small bug. FN was printed out when FD was requested.

---

225. MIMO. 930908

The variables in NAMELIST MIMOIN are listed when the program runs, so that it can be used interactively if desired. (MIMO is usually run from a command procedure.)

---

226. ERAP10B. 930914

Added option to change all negative damping to 0.0 before construction. Previously, this was a hidden option.

---

227. ERAP76A. 930920

Changed the format of the way MIMO time histories are stored.

---

228. ERAP76A. 930920

Fixed significant bug. Program did not function properly unless the specified data array size exactly matched that declared in the FORTRAN DIMENSION statement.

---

229. ERASUBS. 930922

Modified name in OPEN statement for coordinate code files from 'TC' to 'tc' to work properly in case-sensitive operating system (UNIX).

---

230. ERASUBS. 930923

Modified READ(1) statement to read NTIM data samples from each Tape1 record, rather than MTIM. Reading MTIM samples was an obsolete spec. used originally when NODC option existed. This option was removed from code years ago.

---

231. ERAG3. 930923

Added new option to plot singular values in bar plot (histogram) format.

---

232. ERAMLB. 930928

In subroutines GELIM and DETFAC, changed some arrays DIMENSIONed (1) to (*) to avoid fatal runtime error encountered on new Alpha machine (DEC 3000).

---

233. ERAG3B. 930929

Added "MODIFY DEFAULT AXIS NUMBERS?" feature.

---

234. ERAG2B. 931008

Updated this program to get it working properly. It has never been used much in the past.

---

235. ERAG2B. 931013

Modified for use w/ data having FMIN > 0 (zoomed data).

---

236. ERAG1 and ERAG7. 931019

Added capability to plot nonconsecutive data records, i.e., NST_DELTA > 1.

---

237. ERAG1 and ERAG7. 931022

Added hidden option to plot inverted triangles at top of freq.-domain plots at NASTRAN frequencies, as in ERAG15.

---

238. ERAG1 and ERAG7. 931029

Fixed bug. The number of points Fourier transformed for freq.-domain plots was inadvertently calculated as MAX(NTIMTP,NTIMFT), where NTIMTP=no. of time samples to plot and NTIMFT=requested no. of pts to Fourier transform. Fixed so that NTIMFT points are plotted. In practice, usually NTIMFT=NTIMTP so this bug went unnoticed.

---

239. ERAP26, option 13. 931104

New program to add a skewed dof to a mode shape .UNV file. Developed in order to add skewed dofs for shakers 1 & 3 to Mini-Mast .UNV file, for demo problem in User's Guide.

---

240. ERAG15. 931105

Added warning message if a location no. is found in the Tape88 file but

does not appear in the .LOC file.

APPENDIX I - GUIDELINES FOR SELECTING NCH AND NRH

I.1 Selecting NCH and NRH for Modal Test Applications

• Filter data to include approximately 30-50 modes (max.) in the analysis bandwidth.

• Select NCH = approximately 4 to 8 times the estimated number of modes.

- NCH = 6 x No. Modes often used.

- Round NCH up to a multiple of NIC (for EMAC calculation).

• For small to moderate values of NST (less than approximately 100-200):

- Select NRH = approximately 5 to 20 times NST.

- NRH = 10 x NST often used.

- Round NRH up to a multiple of NST (for EMAC calculation).

• For large values of NST (greater than approximately 100-200):

- Select approximately 10-100 representative measurements. Specify their measurement nos. in the User Input file using KEYDTA=. One approach for selecting measurements using component EMAC results of an initial analysis (Tape55) is illustrated in Section 3.14.

- Alternatively, build one or more "generalized time histories" containing response of all excited modes, store them at the end of each Tape1 file, and specify their number in the User Input file using NGENTH= .

• Use a minimum of approximately 2-3 cycles of data of the lowest-frequency mode.

• Limit frequency dynamic range (ratio of highest frequency mode to lowest frequency mode) to maximum of approximately 30:1.

• Examine Modal Strength Ratio (MSR) and ARATIO results on Tape50. If values are too small for a mode of interest (e.g., MSR < 0.5% and/or ARATIO < 0.01), decrease the analysis window length (NTIM). Such modes have probably decayed below the measurement noise floor.

• Reduction of NTIM may also be necessary with nonlinear data due to changing dynamic properties vs response amplitude.

• With linear data, longer data lengths (NTIM) improve identification results by principle of least-squares.

I.2 Selecting NCH and NRH for Control Applications

The following approach has been used successfully at NASA Langley for selecting NCH and NRH in control applications (typically having approx. 8 inputs and 8 output):

• NIC = No. of inputs (No. of Tape1 files).

• NST = No. of outputs (No. of records in each Tape1 file).

• Select *nblocks* = 20.

• Select NCH = *nblocks* x NIC.

• Select NRH = *nblocks* x NST.

• If min(NCH,NRH) < approx. 6 x No. modes in data, increase *nblocks* until min(NCH,NRH) = approx. 6 x No. modes in data.

• *ntim* (No. of time samples required in each pulse response function) = N1 + (*nblocks* -2)*N2 + (*nblocks* -2)*N3 + 2 + N2LAST + N3LAST.

By default, N1 = N2 = N3 = 1 and N2LAST = N3LAST = 10, so that
ntim (default) = 2 * *nblocks* + 19

APPENDIX J - SINGULAR VALUE TRUNCATION

The following logic is used to select the number of retained singular values during singular-value truncation:

If analysis parameter IORDTU ("IORDER TO USE") does not equal -999 (the default), IORDTU singular values will be retained. This is the method used to select a particular analysis order. In terms of assumed number of modes, IORDTU equals twice the assumed number of modes.

If IORDTU equals -999 (the default), truncation will occur at the smallest order among the following 4 criteria:

1. RNKTOL
2. MXFLAG
3. POFVAR
4. MXORDR

J.1 RNKTOL - Rank Tolerance

This criterion corresponds to truncation at the selected value of D(N)/D(1). The default value of RNKTOL is

$$RNKTL0 = SQRT(NRH*NRH + NCH*NCH) * EPS$$

where EPS is the machine precision. EPS is the smallest floating point number which when added to 1.0 gives a result larger than 1.0. It can be determined with the following FORTRAN program (available in directory ERA$SOURCES):

```
      PROGRAM EPS
C
C      THIS PROGRAM CALCULATES THE SYSTEM-DEPENDENT
C      PARAMETER EPS, DECLARED IN FILE ERASYS.FOR.
C
C      EPS IS THE MACHINE PRECISION, USED IN COMPUTED
C      THE NUMERICAL RANK OF THE ERA DATA MATRIX BASED
C      ON THE SINGULAR VALUES.
C
      X = 1.0
   10 XNEW = X/2.0
      IF (1.0 + XNEW .EQ. 1.0) THEN
       PRINT 20, X
   20  FORMAT(/' EPS =',1PE20.10)
       STOP
      ENDIF
C
```

```
X = XNEW
GO TO 10
END
```

The number of singular values larger than RNKTL0 * D(1) determines the numerical rank of the data matrix based on numerical roundoff errors.

J.2 MXFLAG - Switch for Truncation at Largest Value of D(N)/D(N+1)

MXFLAG is a simple on/off switch (1=on, 0=off) which selects truncation at the largest value of D(N)/D(N+1) when turned on.

J.3 POFVAR - Cumulative Percentage of Data Variance

This criterion corresponds to truncation at the selected value of the running sum of the square of the singular values divided by the total sum of squares of the singular values. By the definition of the singular value decomposition, the total sum of squares of the singular values equals the total sum of squares of the data in the matrix which is decomposed (i.e., the total data variance).

Experience has shown that POFVAR = 99.999 (the default) provides a good default cutoff value for typical, low-noise laboratory data (FRFs).

J.4 MXORDR - Maximum Number of Retained Singular Values

If none of the other 3 criteria selects a smaller number of singular values to retained, truncation will occur at MXORDR. The default value of MXORDR is MIN(NRH,NCH)/2; i.e., have of the total number of singular values are truncated.

These 4 cutoff criteria correspond on a one-to-one basis with the 4 columns of data appearing on the righthand side of the singular-value printer plot on TAPE50. The criterion causing the truncation to occur is indicated by an asterisk appearing to the right of the corresponding column. The row on which the asterisk appears corresponds to the number of retained singular values.

If the truncation order was selected using parameter IORDTU, the corresponding number is indicated on the singular-value printer plot using '<' rather than '*'.

There is one situation that will disable the criteria discussed above. If D(N)/D(N+1) exceeds 20, MXFLAG will be changed to a value of 1 and the other cutoff criteria will be disabled. This will cause truncation to occur at the largest value of D(N)/D(N+1). A warning message is issued to inform the user that this modification of the standard singular-

value truncation logic has occurred. This change in logic will **NOT** occur if a particular value of IORDTU was specified (i.e., if IORDTU does not equal -999, the default).

APPENDIX K - HANKEL MATRIX STRUCTURE

ERA uses impulse response (or free decay) time histories for m initial conditions (inputs) and p response locations (outputs), $y_{ij}(k)$, for $i = 1,2,...,p$, $j = 1,2,...,m$, and $k = 1,2,3,...$ In software terminology, $m = NIC$ and $p = NST$. NIC is an acronym for the Number of Initial Conditions and NST is an acronym for the Number of response STations. By default, NIC = MIC and NST = MST where MIC and MST are FORTRAN array dimensions given in Field 3 of the ERA User Input file. MIC and MST are acronyms for the Maximum permissible values of NIC and NST, respectively. k is the time sample index.

Two "generalized Hankel matrices," $H(0)$ and $H(1)$, are formed as follows:

$$H(k) = \begin{bmatrix} Y_1(k+1) & Y_1(k+2) & \cdots & Y_1(k+t) & Y_1(k+t+\Delta C) \\ Y_2(k+2) & Y_2(k+3) & \cdots & Y_2(k+t+1) & Y_2(k+t+1+\Delta C) \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ Y_2(k+s) & Y_2(k+s+1) & \cdots & Y_2(k+s+t-1) & Y_2(k+s+t-1+\Delta C) \\ Y_2(k+s+\Delta R) & Y_2(k+s+1+\Delta R) & \cdots & Y_2(k+s+t-1+\Delta R) & Y_2(k+s+t-1+\Delta R+\Delta C) \end{bmatrix}$$

for $k = 0,1$.

Submatrices $Y_1(k)$ and $Y_2(k)$ contain data at time instant k. Submatrix $Y_1(k)$ consists of response data for all m initial conditions (inputs) and all p response locations (outputs) at time instant k arranged as follows:

$$Y_1(k) = \begin{bmatrix} y_{11}(k) & y_{12}(k) & \cdots & y_{1m}(k) \\ y_{21}(k) & y_{22}(k) & \cdots & y_{2m}(k) \\ \vdots & \vdots & \ddots & \vdots \\ y_{p1}(k) & y_{p2}(k) & \cdots & y_{pm}(k) \end{bmatrix}$$

Submatrix $Y_2(k)$ is identical to $Y_1(k)$ except with the possible deletion of some rows. If parameter KEYDTA is not specified in Field 4 of the ERA User Input file (the default), $Y_2(k) = Y_1(k)$. If (array) parameter KEYDTA is specified in Field 4 of the ERA User Input file, it designates those rows of $Y_1(k)$ to retain in constructing $Y_2(k)$. For example, if KEYDTA = 2,5,6,9, then

$$Y_2(k) = \begin{bmatrix} y_{21}(k) & y_{22}(k) & \cdots & y_{2m}(k) \\ y_{51}(k) & y_{52}(k) & \cdots & y_{5m}(k) \\ y_{61}(k) & y_{62}(k) & \cdots & y_{6m}(k) \\ y_{91}(k) & y_{92}(k) & \cdots & y_{9m}(k) \end{bmatrix}$$

By default, every block row and column of $H(k)$ is shifted by 1 time sample from the previous block row and column[240], except for the last block row and column.[241] By default, the last block row and column are shifted by 10 time samples from the previous row and column (i.e., $\Delta R = \Delta C = 10$).[242] This additional shifting of the last block row and column is done in order to compute EMAC values (Ref. 8). In software terminology, $\Delta R = N2LAST$ and $\Delta C = N3LAST$.

The total number of rows and columns in $H(0)$ and $H(1)$ is specified by User Parameters NRH and NCH, respectively. NRH and NCH are acronyms for the Number of Rows in the Hankel matrices and the Number of Columns in the Hankel matrices, respectively. By default, NRH = MRH and NCH = MCH where MRH and MCH are FORTRAN array dimensions given in Field 3 of the ERA User Input file. MRH and MCH are acronyms for the Maximum permissible values of NRH and NCH, respectively. The values of s and t (used in constructing $H(k)$) are calculated internally by the software based on the specified values of NRH, NCH, NST, NIC, and NSTBOT, where NSTBOT is the number of response locations listed in KEYDTA.

[240]The $Y_1(k)$ and $Y_2(k)$ submatrices constitute the various "block rows" and "block columns" of $H(k)$.

[241]The default time shifts of 1 time sample between the block rows or block columns can be modified by specifying parameter N2 or N3, respectively, in Field 4 of the ERA User Input file.

[242]The default time shifts of 10 time samples between the last and second-last block rows or between the last and second-last block columns can be modified by specifying parameters N2LAST or N3LAST, respectively, in Field 4 of the ERA User Input file.

APPENDIX L - LISTINGS OF MATLAB .M FILES

build_ac_modal.m

```
% BUILD_AC_MODAL. Build ac_modal matrix from Tape79 results:
%  iorder    = model order (no. of states)
%  nreval    = no. of identified real eigenvalues
%  s_evalues = identified s-domain eigenvalues
%
% R. Pappa  6-30-92
%
fprintf('BUILD_AC_MODAL. Build continuous-time modal A matrix (ac_modal) from
s_evalues.\n\n')
fprintf('Total no. of states (iorder) = %g\n',iorder)
fprintf(' consisting of:\n')
fprintf('%g real eigenvalues (nreval)\n',nreval)
fprintf('%g complex-conjugate pairs of eigenvalues ((iorder-nreval)/2)\n\n', (iord
nreval)/2)
%
ac_modal = diag(s_evalues(:,1));
for i=nreval+1:2:iorder-1,ac_modal(i,i+1)=s_evalues(i,2);end
for i=nreval+2:2:iorder,  ac_modal(i,i-1)=s_evalues(i,2);end
```

build_ad_modal.m

```
% BUILD_AD_MODAL. Build ad_modal matrix from Tape79 results:
%  iorder    = model order (no. of states)
%  nreval    = no. of identified real eigenvalues
%  z_evalues = identified z-domain eigenvalues
%
% R. Pappa  6-30-92
%
fprintf('BUILD_AD_MODAL. Build discrete-time modal A matrix (ad_modal) from
z_evalues.\n\n')
fprintf('Total no. of states (iorder) = %g\n',iorder)
fprintf(' consisting of:\n')
fprintf('%g real eigenvalues (nreval)\n',nreval)
fprintf('%g complex-conjugate pairs of eigenvalues ((iorder-nreval)/2)\n\n', (iord
nreval)/2)
%
ad_modal = diag(z_evalues(:,1));
for i=nreval+1:2:iorder-1,ad_modal(i,i+1)=z_evalues(i,2);end
for i=nreval+2:2:iorder,  ad_modal(i,i-1)=z_evalues(i,2);end
```

eraw.m

```
function [L,psi,mpf,emac,mpc,cmi,sv,fd,zetap,clktime]=eraw(YY,q,p,sf,r,s,time,trun
% ERAW.M:  [l,psi,mpf,emac,mpc,cmi,sv,fd,zetap,clktime]=eraw(yy,q,p,sf,r,s,time,tr
%
```

```
%         ERAW.M  program uses the Eigensystem Realization Algorithm for
%         the modal parameters identification and model reduction of
%         dynamic system from time series test data, where:
%
%              YY = Y(1:m), (q.(p.m)) matrix of time series data set;
%            Y(k) = C.A^k.B, (q.p) matrix of measurement data;
%               q = number of measurement points;
%               p = number of excitation points;
%               m = number of time samples;
%              sf = sampling frequency (Hz);
%               r = no. of blocks in row direction of Hankel matrix;
%               s = no. of blocks in column direction of Hankel matrix;
%            time = [n1,n2,n3,n2last,n3last], time samples shifts;
%           trunc = [rnktol,mxflag,pofvar,mxordr,iordtu], truncation parameters;
%               L = eigenvalues (rad/sec);
%             PSI = eigenvectors (m);
%             MPF = modal participation factors (J);
%            EMAC = extended modal amplitude coherence;
%             MPC = modal phase collinearity;
%             CMI = consistent-mode indicator.
%              sv = singular values
%          clktime = elapsed time
%               fd = damped nat. freqs (Hz)
%           zetap = damping factors (%)

%           n1 = time samples shift between two Hankel matrices;
%           n2 = time samples shift in row direction of Hankel matrix;
%           n3 = time samples shift in column direction of Hankel matrix;
%         n2last = last time sample shift in row direc. of Hankel matrix;
%         n3last = last time sample shift in col. direc. of Hankel matrix;
%       rnktol = rank tolerance, truncation at value of S(i)/S(1);
%       mxflag = if mxflag=1, truncation at largest value of S(i)/S(i+1);
%        pofvar = truncation at percentage of cumulative data variance;
%         mxordr = max. no. of singular-values retained.
%
%        Reference:
%
%        Juang, Jer-Nan; Pappa, Richard S.;
%        An Eigensystem Realization Algorithm for Modal Parameter
%        Identification and Model Reduction; AIAA Journal of Guidance,
%        Control, and Dynamics; Vol. 8, No. 5, Sept.-Oct. 1985;
%        pp. 620-627.
%
%        Pappa, Richard S.; Shenk, Axel; Niedbal, Norbert; Klusowski,
%        Erhard;
%        Comparison of two dissimilar modal identification techniques;
%        International Forum on Aeroelasticity and Structural Dynamics,
%        Aachen, Germany, June 3-6, 1991;
%
%        Pappa, Richard;
%        A Consistent-Mode Indicator For ERA
%        Abstract submited for
%        AIAA Dynamics Specialists Conference
%        Dallas, Texas, April 16-17, 1992
```

```
%
%       Version 1.0
%       Walter Ponge-Ferreira
%       DLR WB-AE - Institut fuer Aeroelastik
%       Goettingen, 29 November 1991.
%

tstart=clock;

echo off

NARGIN=7;

% ---> ERA Solution:

% Form the generalized Hankel matrix:

YY=YY(1:q,:);
[q,m]=size(YY);
m=fix(m/p);
t=[0:p-1]*m+ones(1,p);
n1=time(1);
n2=time(2);
n3=time(3);
n2last=time(4);
n3last=time(5);
H0=[];
H1=[];
for i=0:r-2
   aux0=[];
   aux1=[];
   for j=0:s-2
      aux0=[aux0 YY(:,t+ones(t)*(n2*i+n3*j))];
      aux1=[aux1 YY(:,t+ones(t)*(n2*i+n3*j+n1))];
   end
   aux0=[aux0 YY(:,t+ones(t)*(n2*i+n3*(s-2)+n3last))];
   aux1=[aux1 YY(:,t+ones(t)*(n2*i+n3*(s-2)+n3last+n1))];
   H0=[H0;aux0];
   H1=[H1;aux1];
end
aux0=[];
aux1=[];
for j=0:s-2
   aux0=[aux0 YY(:,t+ones(t)*(n2*(r-2)+n3*j+n2last))];
   aux1=[aux1 YY(:,t+ones(t)*(n2*(r-2)+n3*j+n2last+n1))];
end
aux0=[aux0 YY(:,t+ones(t)*(n2*(r-2)+n3*(s-2)+n2last+n3last))];
aux1=[aux1 YY(:,t+ones(t)*(n2*(r-2)+n3*(s-2)+n2last+n3last+n1))];
H0=[H0;aux0];
H1=[H1;aux1];

clear aux1 aux2

% Decompose H0 using singular-value decomposition:
```

```
[U,S,V]=svd(H0);

% Determine the order of the system:

% Set truncation parameters:
if nargin<NARGIN
   rnktol=0.10;  % rank tolerance, S(i)/S(1);
   mxflag=1;     % flag for truncation at largest S(i)/S(i+1);
   pofvar=0.99;   % truncation at percentage of cumulative variance;
   mxordr=length(diag(S))/2; % max. no. of singular-values;
else
   if length(trunc)==1;
      rnktol=0.00;
      mxflag=0;
      pofvar=1.01;
      mxordr=min([trunc(1),length(diag(S))/2]);
   else
      rnktol=trunc(1);
      mxflag=trunc(2);
      pofvar=trunc(3);
      mxordr=min([trunc(4),length(diag(S))/2]);
   end
end

TRUNC=[];
N=[];
sv=diag(S);
n=length(sv);
TRUNC(:,1)=sv./sv(1);
N(1)=length(find(TRUNC(:,1)>=rnktol));
TRUNC(1:n-1,2)=sv(1:n-1)./sv(2:n);
TRUNC(n,2)=0;
N(2)=max(find(TRUNC(:,2)==max(TRUNC(:,2))));
for i=1:n
   TRUNC(i,3)=sum(sv(1:i).^2)./sum(sv.^2);
end
N(3)=length(find(TRUNC(:,3)<=pofvar));
if mxflag,
   n=min([N,mxordr]);
else
   n=min([N([1,3]),mxordr]);
end

iordtu=trunc(5);
if (iordtu~=0),n=iordtu;,end

S=S(1:n,1:n);
U=U(:,1:n);
V=V(:,1:n);

clear aux

% Construct the minimum-order realization (A,B,C):
```

```
A=(S^(-.5))*U.'*H1*V*(S^(-.5));
B=(S^0.5)*V.';
C=U*(S^0.5);

% Find the eigensolution:

Ep=[eye(p,p);zeros((s-1)*p,p)];
Eq=[eye(q,q);zeros((r-1)*q,q)];

[W,D]=eig(A);
MPF=inv(W)*B*Ep;
PSI=Eq.'*C*W;

% ---> Calculation of CMI:

% Extended Modal Amplitude Coherence - EMAC:

% Input EMAC:

Ep=[zeros((s-1)*p,p);eye(p,p)];
MPFi=inv(W)*B*Ep;
MPFp=(diag(D).^(((r-2)*n2+n2last)./n1)*ones(1,p)).*MPF;

SS=abs(MPFi)./abs(MPFp);
i=(SS<=ones(SS));
SS=SS.*i+(ones(SS)./SS).*(ones(SS)-i);
WW=ones(MPFi)-(abs(angle(MPFi./MPFp))/(pi/4));
i=(WW>=zeros(WW));
WW=WW.*i;
EMACi=SS.*WW;

% Output EMAC:

Eq=[zeros((r-1)*q,q);eye(q,q)];
PSIo=Eq.'*C*W;
PSIp=PSI.*(ones(q,1)*(diag(D).'.^(((s-2)*n3+n3last)./n1)));

SS=abs(PSIo)./abs(PSIp);
i=(SS<=ones(SS));
SS=SS.*i+(ones(SS)./SS).*(ones(SS)-i);
WW=ones(PSIo)-(abs(angle(PSIo./PSIp))/(pi/4));
i=(WW>=zeros(WW));
WW=WW.*i;
EMACo=SS.*WW;

clear i SS WW PSIo PSIp MPFi MPFp

% Condensed EMAC:

EMAC=(ones(1,q)*(EMACo.*(abs(PSI).^2))./(ones(1,q)*(abs(PSI).^2)).*...
  (ones(1,p)*((EMACi.').*(abs(MPF.').^2)))./(ones(1,p)*(abs(MPF.').^2));

% Modal Phase Collinearity:
```

```
Sxx=ones(1,q)*(real(PSI).^2);
Syy=ones(1,q)*(imag(PSI).^2);
Sxy=ones(1,q)*(real(PSI).*imag(PSI));

MPC=(((Syy-Sxx).^2)+4*(Sxy.^2))./((Syy+Sxx).^2);

clear Sxx Syy Sxy mu tal

% Consistent-Mode Indicator:

CMI=EMAC.*MPC;

% Select the Solution:

i=find(imag(diag(D))>0);
n=min([n length(i)]);
i=i(1:n);
D=D(i,i);
PSI=PSI(:,i);
MPF=MPF(i,:);
EMAC=EMAC(i);
MPC=MPC(i);
CMI=CMI(i);

% Transform from the discrete to the continuous domain:

L=log(diag(D)).*sf./n1;

% Normalize Eigenvector:

PSI=PSI./(ones(q,1)*max(PSI));

% --------

sigma=real(L);
wn=imag(L);
fd0=wn/(2*pi);
zetap0=-sigma./wn*100;

% sort results (ascending freq)

[fd,isort]=sort(fd0);
zetap=zetap0(isort);
emac=EMAC(isort)'*100;
mpc=MPC(isort)'*100;
cmi=CMI(isort)'*100;
psi=PSI(:,isort);
mpf=MPF(isort,:);

clktime=etime(clock,tstart);
return
```

figs4to6_theory_a.m

```
% figs4to6_theory_a.m
%
% Calculate and plot FRFs of continuous and discrete systems
% for ERA User's Guide, Figs. 2-4 thru 2-6.
%
% ACCELERATION RESPONSE
%
% R. Pappa  5-25-93
%

j = sqrt(-1);

m1 = 0.8; m2 = 1.5; g = 0.1; k = 10;

M = [m1 0 ; 0 m2]
G = [2*g -g ; -g 2*g]
K = [2*k -k ; -k 2*k]

ac = [zeros(2) eye(2) ; -M\K -M\G]
bc = [zeros(2) ; inv(M)]
c  = [-M\K -M\G]
d  = inv(M)

sf = 2.0;
Nyquist_freq = sf/2
nflines = 500

df = 1/nflines;
f = [df : df : 1];
w = 2 * pi * f;

innum=1; outnum = 1;
[magc,phasec] = bode(ac,bc,c(outnum,:),d(outnum,:),innum,w);
% cc = cos(phasec/180*pi); ss = sin(phasec/180*pi);
% phasec = atan2(ss,cc)/pi*180;

dt = 1/sf;
[a,b] = c2d(ac,bc,dt);

[magd,phased] = dbode(a,b,c(outnum,:),d(outnum,:),dt,innum,w);
% cc = cos(phased/180*pi); ss = sin(phased/180*pi);
% phased = atan2(ss,cc)/pi*180;

% Plot continuous FRF
clg
subplot(211),semilogy(f,abs(magc),'k-'),axis([0 1 1e-3 1e2])
ylabel('Magnitude')
title('Continuous System A/F FRF')
subplot(212),plot(f,phasec,'k-'),axis('auto')
xlabel('Frequency, Hz'),ylabel('Phase, deg.')
pause
```

```
% Plot discrete FRF
clg
subplot(211),semilogy(f,abs(magd),'k-'),axis([0 1 1e-3 1e2])
ylabel('Magnitude')
title('Discrete System A/F FRF')
subplot(212),plot(f,phased,'k-'),axis('auto')
xlabel('Frequency, Hz'),ylabel('Phase, deg.')
pause

% Overlay continuous and discrete FRFs
clg
subplot(211)
semilogy(f,abs(magc),'k-'),axis([0 1 1e-3 1e2])
hold on,semilogy(f,abs(magd),'k--'),hold off
ylabel('Magnitude')
title('Continuous System = Solid line, Discrete System = Dashed line')
subplot(212)
plot(f,phasec,'k-'),axis('auto')
hold on,plot(f,phased,'k--'),hold off
xlabel('Frequency, Hz'),ylabel('Phase, deg.')
pause
```

figs4to6_theory_d.m

```
% figs4to6_theory_d.m
%
% Calculate and plot FRFs of continuous and discrete systems
% for ERA User's Guide, Figs. 2-4 thru 2-6.
%
% DISPLACEMENT RESPONSE
%
% R. Pappa  5-25-93
%

j = sqrt(-1);

m1 = 0.8; m2 = 1.5; g = 0.1; k = 10;

M = [m1 0 ; 0 m2]
G = [2*g -g ; -g 2*g]
K = [2*k -k ; -k 2*k]

ac = [zeros(2) eye(2) ; -M\K -M\G]
bc = [zeros(2) ; inv(M)]
c  = [eye(2) zeros(2)]
d  = zeros(2)

sf = 2.0;
Nyquist_freq = sf/2
nflines = 500

df = 1/nflines;
```

```
f = [df : df : 1];
w = 2 * pi * f;

innum=1; outnum = 1;
[magc,phasec] = bode(ac,bc,c(outnum,:),d(outnum,:),innum,w);
% cc = cos(phasec/180*pi); ss = sin(phasec/180*pi);
% phasec = atan2(ss,cc)/pi*180;

dt = 1/sf;
[a,b] = c2d(ac,bc,dt);

[magd,phased] = dbode(a,b,c(outnum,:),d(outnum,:),dt,innum,w);
% cc = cos(phased/180*pi); ss = sin(phased/180*pi);
% phased = atan2(ss,cc)/pi*180;

% Plot continuous FRF
clg
subplot(211);semilogy(f,abs(magc),'k-'),axis([0 1 1e-3 1e1])
ylabel('Magnitude')
title('Continuous System D/F FRF')
subplot(212),plot(f,phasec,'k-'),axis('auto')
xlabel('Frequency, Hz'),ylabel('Phase, deg.')
pause

% Plot discrete FRF
clg
subplot(211);semilogy(f,abs(magd),'k-'),axis([0 1 1e-3 1e1])
ylabel('Magnitude')
title('Discrete System D/F FRF')
subplot(212),plot(f,phased,'k-'),axis('auto')
xlabel('Frequency, Hz'),ylabel('Phase, deg.')
pause

% Overlay continuous and discrete FRFs
clg
subplot(211)
semilogy(f,abs(magc),'k-'),axis([0 1 1e-3 1e1])
hold on,semilogy(f,abs(magd),'k--'),hold off
ylabel('Magnitude')
title('Continuous System = Solid line, Discrete System = Dashed line')
subplot(212)
plot(f,phasec,'k-'),axis('auto')
hold on,plot(f,phased,'k--'),hold off
xlabel('Frequency, Hz'),ylabel('Phase, deg.')
pause
```

hz_from_hs_and_zoh.m

```
function hz = hz_from_hs_and_zoh(ac,bc,c,d,dt)
%
% Sample calling sequence:
%  hz = hz_from_hs_and_zoh(ac,bc(:,1),c(1,:),d(1,1),dt);
%
```

```
% Calculate h(z) by multiplying h_zoh (zero-order hold)
% by h(s) and then discretize by folding continuous spectrum
% over 'nstrips' frequency strips.
%
% Input parameters: ac,bc,c,d = continuous SISO model
%                   dt = sampling interval
% Output parameters: hz = frf of discrete system assuming zoh
%
% R. Pappa  8-27-92
%

% SISO model must be specified
[nst,nic] = size(d);
if nst ~= 1
 error('No. outputs > 1. Model must be SISO.')
end
if nic ~= 1
 error('No. inputs > 1. Model must be SISO.')
end

% data statements:
nstrips = 10
nfpts_total = 10000
% start plots at 0.02 Hz
flinetp = 0.02 / (1/dt/2*nstrips) * nfpts_total;

sf = 1/dt;
Nyquist_frequency = sf/2
ws = 2 * pi * sf;
fmax_plotted = nstrips * sf/2;
df = fmax_plotted / nfpts_total;
f = [0 : df : df * (nfpts_total - 1)]';
lenf = length(f);
w = 2 * pi * f;

% Calculate hs w/ d
[mag,phased,w] = bode(ac,bc,c,d,1,w);
phase = phased/180*pi;
hs_with_d = mag .* (cos(phase) + j*sin(phase));
% Plot every nstrips pt (adequate for graphics purposes)
clg
subplot(2,1,1)
semilogy(f(flinetp:nstrips:lenf),mag(flinetp:nstrips:lenf))
title('hs (w/ d matrix)'),ylabel('Magnitude')
subplot(2,1,2)
plot(f(flinetp:nstrips:lenf),phased(flinetp:nstrips:lenf))
xlabel('Frequency, Hz'),ylabel('Phase, deg')
pause

% Now, calculate hs w/o d
[mag,phased,w] = bode(ac,bc,c,0.0,1,w);
phase = phased/180*pi;
hs = mag .* (cos(phase) + j*sin(phase));
% Plot every nstrips pt (adequate for graphics purposes)
```

```
clg
subplot(2,1,1)
semilogy(f(flinetp:nstrips:lenf),mag(flinetp:nstrips:lenf))
title('hs (w/o d matrix)'),ylabel('Magnitude')
subplot(2,1,2)
plot(f(flinetp:nstrips:lenf),phased(flinetp:nstrips:lenf))
xlabel('Frequency, Hz'),ylabel('Phase, deg')
pause

% calculate h of zero-order hold
piwdws = pi * w / ws;
h_zoh = 2*pi/ws .* sin(piwdws) ./ piwdws .* exp(-j * piwdws);
h_zoh = h_zoh * sf; % normalize to unity gain at DC
h_zoh(1) = 1.0;  % remove NaN at f = 0
mag = abs(h_zoh); phased = angle(h_zoh)/pi*180;
% Plot every nstrips pt (adequate for graphics purposes)
clg
subplot(2,1,1)
plot(f(1:nstrips:lenf),mag(1:nstrips:lenf))
title('h_zoh'),ylabel('Magnitude')
subplot(2,1,2)
plot(f(1:nstrips:lenf),phased(1:nstrips:lenf))
xlabel('Frequency, Hz'),ylabel('Phase, deg')
pause

h_total = h_zoh .* hs;
mag = abs(h_total); phased = angle(h_total)/pi*180;
% Plot every nstrips pt (adequate for graphics purposes)
clg
subplot(2,1,1)
semilogy(f(flinetp:nstrips:lenf),mag(flinetp:nstrips:lenf))
title('h_zoh * hs_w/o_d'),ylabel('Magnitude')
subplot(2,1,2)
plot(f(flinetp:nstrips:lenf),phased(flinetp:nstrips:lenf))
xlabel('Frequency, Hz'),ylabel('Phase, deg')
pause

% fold h_total back and forth (alias the higher frequencies)
% into the interval from 0 to Nyquist frequency
len = length(h_total);
h_aliased = zeros(len/nstrips,1);
for strip = 1:nstrips
 startel = (strip - 1)*len/nstrips + 1;
 endel = startel + len/nstrips - 1;
 h_this_strip = h_total(startel:endel);
 if rem(strip,2) == 0
  h_this_strip = conj(flipud(h_this_strip));
 end
 h_aliased = h_aliased + h_this_strip;
end

f2 = f(1:length(h_aliased));
lenf2 = length(f2);
mag = abs(h_aliased); phased = angle(h_aliased)/pi*180;
```

```
clg
subplot(2,1,1)
semilogy(f2,mag)
title('aliased (h_zoh * hs_w/o_d)'),ylabel('Magnitude')
subplot(2,1,2)
plot(f2,phased)
xlabel('Frequency, Hz'),ylabel('Phase, deg')
pause

% Now, add the d matrix
h_aliased = h_aliased + d;
f2 = f(1:length(h_aliased));
lenf2 = length(f2);
mag = abs(h_aliased); phased = angle(h_aliased)/pi*180;
clg
subplot(2,1,1)
semilogy(f2(flinetp:lenf2),mag(flinetp:lenf2))
title('[aliased (h_zoh * hs)] + d'),ylabel('Magnitude')
subplot(2,1,2)
plot(f2(flinetp:lenf2),phased(flinetp:lenf2))
xlabel('Frequency, Hz'),ylabel('Phase, deg')
pause

[a,b] = c2d(ac,bc,dt);
w2 = 2 * pi * f2;
[dmag,dphased,w] = dbode(a,b,c,d,dt,1,w2);
dphase = dphased/180. * pi;
hz = dmag .* (cos(dphase) + j*sin(dphase));
clg
subplot(2,1,1)
semilogy(f2(flinetp:lenf2),dmag(flinetp:lenf2))
title('hz'),ylabel('Magnitude')
subplot(2,1,2)
plot(f2(flinetp:lenf2),dphased(flinetp:lenf2))
xlabel('Frequency, Hz'),ylabel('Phase, deg')
pause

mag1 = abs(h_aliased); phased1 = angle(h_aliased)/pi*180;
mag2 = abs(hz)       ; phased2 = angle(hz)/pi*180;
clg
subplot(2,1,1)
semilogy(f2(flinetp:lenf2),mag1(flinetp:lenf2),'k-'),hold on
semilogy(f2(flinetp:lenf2),mag2(flinetp:lenf2),'k--'),hold off
title('[aliased (h_zoh * hs)] + d (solid line) vs hz (dashed line)')
ylabel('Magnitude')
subplot(2,1,2)
plot(f2(flinetp:lenf2),phased1(flinetp:lenf2),'k-'),hold on
plot(f2(flinetp:lenf2),phased2(flinetp:lenf2),'k--'),hold off
xlabel('Frequency, Hz'),ylabel('Phase, deg')
pause

ratio = hz ./ h_aliased;
mag = abs(ratio); phased = angle(ratio)/pi*180;
clg
```

```
subplot(2,1,1)
plot(f2(flinetp:lenf2),mag(flinetp:lenf2))
title('hz / [aliased (h_zoh * hs)] + d'),ylabel('Magnitude')
subplot(2,1,2)
plot(f2(flinetp:lenf2),phased(flinetp:lenf2))
xlabel('Frequency, Hz'),ylabel('Phase, deg')
```

irfs_af_theory.m

```
% irfs_af_theory.m
%
% Compute impulse response of continous system by oversampling
% 100 times, and compare with IRF computed by IFFT.
%
% Save all results as ASCII files
%
% ACCELERATION RESPONSE
%
% R. Pappa  6-23-93
%

j = sqrt(-1);

m1 = 0.8; m2 = 1.5; g = 0.1; k = 10;

M = [m1 0 ; 0 m2]
G = [2*g -g ; -g 2*g]
K = [2*k -k ; -k 2*k]

ac = [zeros(2) eye(2) ; -M\K -M\G]
bc = [zeros(2) ; inv(M)]
c  = [-M\K -M\G]
d  = inv(M)

sf = 4.0  % Extend to fmax = 2 Hz for FRF calculation
nflines = 250
dt = 1/sf;
df = (sf/2)/nflines;
f = [0 : df : sf/2];
w = 2 * pi * f;

factor = 100
sf_factor = factor * sf  % oversample by 'factor' to obtain good IRF
                         % using lsim
dt_factor = 1/sf_factor;

ntpts = 2 * nflines
ntpts_factor = factor * ntpts;
t_factor = [0:dt_factor:(ntpts_factor-1)*dt_factor]';

u_factor = zeros(size(t_factor));
u_factor(1) = 2/dt_factor; % lsim_foh uses linear interpolation
                           % of u (trianglur rather than rectangular
```

```
                          % excitation history, thus factor of 2 on
                          % u_factor(1) is needed.
% innum=1; outnum = 1;
for innum = 1:2
for outnum = 1:2
innum,outnum

% Use Version 3 LSIM (lsim_foh) which interpolates the input using
%  a first-order hold.

y_factor = lsim_foh(ac,bc(:,innum),c(outnum,:),d(outnum,innum),...
u_factor,t_factor);

% Extract every factor'th data point in response

fence_factor = [1:factor:ntpts_factor]';
t0 = t_factor(fence_factor); lent0 = length(t0);
y0 = y_factor(fence_factor);

% Compare with IRF computed as IFFT of FRF

[magc,phasec] = bode(ac,bc,c(outnum,:),d(outnum,:),innum,w);
phasec_rad = phasec/180. * pi;
gs = magc .* (cos(phasec_rad) + j*sin(phasec_rad));

% calculate irf using 0 - sf/2 data

gs(1) = real(gs(1));gs(ntpts/2+1)=real(gs(ntpts/2+1));
gs(ntpts/2+2:ntpts) = conj(flipud(gs(2:ntpts/2)));

y_ifft_gs = ifft(gs) / dt;
y_ifft_gs = y_ifft_gs(1:length(t0));

% Plot Results

clf
real_y_ifft_gs = real(y_ifft_gs);
plot(t0(1:lent0),real_y_ifft_gs(1:lent0))
axis;
xlabel('Time, sec'),ylabel('A/F Impulse Response')
title('A/F IRF from IFFT of FRF')
axis_vect = axis;

% Store this irf in irf_ifft_innum_all
if innum == 1
 irf_ifft_1_all(:,outnum) = real_y_ifft_gs(1:lent0);
elseif innum == 2
 irf_ifft_2_all(:,outnum) = real_y_ifft_gs(1:lent0);
else
 error('innum must be 1 or 2')
end

pause
```

```
clf
plot(t0(1:lent0),y0(1:lent0))
axis(axis_vect);
xlabel('Time, sec'),ylabel('A/F Impulse Response')
title('A/F IRF from time simulation')

% Store this irf in irf_lsim_innum_all
if innum == 1
 irf_lsim_1_all(:,outnum) = y0(1:lent0);
elseif innum == 2
 irf_lsim_2_all(:,outnum) = y0(1:lent0);
else
 error('innum must be 1 or 2')
end

pause

% Plot difference: time simulation - IFFT result

y_diff = y0(1:lent0) - real_y_ifft_gs(1:lent0);
clf
plot(t0(1:lent0),y_diff)
axis_vect3 = [axis_vect(1:2) axis_vect(3)/10 axis_vect(4)/10];
axis(axis_vect3);
xlabel('Time, sec'),ylabel('A/F Impulse Response')
title('Difference: Time Simulation - IFFT')

pause

% Now, make overlay plot of beginning of both functions

len_short = 50;
% t0_short = t0(1:len_short);

clf
plot(t0(1:len_short),real(y_ifft_gs(1:len_short)),'o')
axis_vect2 = [0 14 axis_vect(3:4)];
axis(axis_vect2);
hold on
plot(t0(1:len_short),y0(1:len_short),'+')
plot(t0(1:len_short),y0(1:len_short),'k-')
plot(t0(1:len_short),real(y_ifft_gs(1:len_short)),'k--')
hold off
xlabel('Time, sec'),ylabel('A/F Impulse Response')
title('Time Simulation = Solid line (+), IFFT of FRF = Dashed line (o)')

pause

end % End of outnum=1:2 loop
end % End of innum=1:2 loop

% Save all results on disk in ASCII format

save irfs_af_lsim_1.asc irf_lsim_1_all /ascii
```

```
save irfs_af_lsim_2.asc irf_lsim_2_all /ascii
save irfs_af_ifft_1.asc irf_ifft_1_all /ascii
save irfs_af_ifft_2.asc irf_ifft_2_all /ascii
```

irfs_df_theory.m

```
% irfs_df_theory.m
%
% Compute impulse response of continous system by oversampling
% 100 times, and compare with IRF computed by IFFT.
%
% Save all results as ASCII files
%
% DISPLACEMENT RESPONSE
%
% R. Pappa  6-23-93
%

j = sqrt(-1);

m1 = 0.8; m2 = 1.5; g = 0.1; k = 10;

M = [m1 0 ; 0 m2]
G = [2*g -g ; -g 2*g]
K = [2*k -k ; -k 2*k]

ac = [zeros(2) eye(2) ; -M\K -M\G]
bc = [zeros(2) ; inv(M)]
c  = [eye(2) zeros(2)]
d  = zeros(2)

sf = 4.0  % Extend to fmax = 2 Hz for FRF calculation
nflines = 250
dt = 1/sf;
df = (sf/2)/nflines;
f = [0 : df : sf/2];
w = 2 * pi * f;

factor = 100
sf_factor = factor * sf  % oversample by 'factor' to obtain good IRF
                         % using lsim
dt_factor = 1/sf_factor;

ntpts = 2 * nflines
ntpts_factor = factor * ntpts;
t_factor = [0:dt_factor:(ntpts_factor-1)*dt_factor]';

u_factor = zeros(size(t_factor));
u_factor(1) = 2/dt_factor; % lsim_foh uses linear interpolation
                           % of u (trianglur rather than rectangular
                           % excitation history, thus factor of 2 on
                           % u_factor(1) is needed.
% innum=1; outnum = 1;
```

```
for innum = 1:2
for outnum = 1:2
innum,outnum

% Use Version 3 LSIM (lsim_foh) which interpolates the input using
%  a first-order hold.

y_factor = lsim_foh(ac,bc(:,innum),c(outnum,:),d(outnum,innum),...
u_factor,t_factor);

% Extract every factor'th data point in response

fence_factor = [1:factor:ntpts_factor]';
t0 = t_factor(fence_factor);
y0 = y_factor(fence_factor);

% Compare with IRF computed as IFFT of FRF

[magc,phasec] = bode(ac,bc,c(outnum,:),d(outnum,:),innum,w);
phasec_rad = phasec/180. * pi;
gs = magc .* (cos(phasec_rad) + j*sin(phasec_rad));

% calculate irf using 0 - sf/2 data

gs(1) = real(gs(1));gs(ntpts/2+1)=real(gs(ntpts/2+1));
gs(ntpts/2+2:ntpts) = conj(flipud(gs(2:ntpts/2)));

y_ifft_gs = ifft(gs) / dt;
y_ifft_gs = y_ifft_gs(1:length(t0));

% Plot Results

clf
plot(t0,y0)
xlabel('Time, sec'),ylabel('D/F Impulse Response')
title('D/F IRF from time simulation')

% Store this irf in irf_lsim_innum_all
if innum == 1
 irf_lsim_1_all(:,outnum) = y0;
elseif innum == 2
 irf_lsim_2_all(:,outnum) = y0;
else
 error('innum must be 1 or 2')
end

pause

clf
real_y_ifft_gs = real(y_ifft_gs);
plot(t0,real_y_ifft_gs)
xlabel('Time, sec'),ylabel('D/F Impulse Response')
title('D/F IRF from IFFT of FRF')
```

```
% Store this irf in irf_ifft_innum_all
if innum == 1
 irf_ifft_1_all(:,outnum) = real_y_ifft_gs;
elseif innum == 2
 irf_ifft_2_all(:,outnum) = real_y_ifft_gs;
else
 error('innum must be 1 or 2')
end

pause

% Plot difference: time simulation - IFFT result

y_diff = y0 - real_y_ifft_gs;
clf
plot(t0,y_diff)
xlabel('Time, sec'),ylabel('D/F Impulse Response')
title('Difference: Time Simulation - IFFT')

pause

% Now, make overlay plot of beginning of both functions

len_short = 50;
t0_short = t0(1:len_short);

clf
plot(t0_short,y0(1:len_short),'k-')
hold on
plot(t0_short,real_y_ifft_gs(1:len_short),'k--')
plot(t0_short,y0(1:len_short),'+')
plot(t0_short,real_y_ifft_gs(1:len_short),'o')
hold off
xlabel('Time, sec'),ylabel('D/F Impulse Response')
title('Time Simulation = Solid line (+), IFFT of FRF = Dashed line (o)')

pause

end % End of outnum=1:2 loop
end % End of innum=1:2 loop

% Save all results on disk in ASCII format

save irfs_df_lsim_1.asc irf_lsim_1_all /ascii
save irfs_df_lsim_2.asc irf_lsim_2_all /ascii
save irfs_df_ifft_1.asc irf_ifft_1_all /ascii
save irfs_df_ifft_2.asc irf_ifft_2_all /ascii
```

lsim_foh.m

```
function  [yout,x] = lsim_foh(a, b, c, d, u, t, x0)
% This is the Version 3.0 LSIM which interpolates the input
% using a first-order hold
```

```
%
%LSIM   Simulation of continuous-time linear systems to arbitrary inputs.
%       LSIM(A,B,C,D,U,T) plots the time response of the linear system:
%
%                       x = Ax + Bu
%                       y = Cx + Du
%       to the input time history U. Matrix U must have as many columns as
%       there are inputs, U.  Each row of U corresponds to a new time
%       point, and U must have LENGTH(T) rows.  The time vector T must be
%       regularly spaced.  LSIM(A,B,C,D,U,T,X0) can be used if initial
%       conditions exist.
%
%       LSIM(NUM,DEN,U,T) plots the time response of the polynomial
%       transfer function  G(s) = NUM(s)/DEN(s)  where NUM and DEN contain
%       the polynomial coefficients in descending powers of s.  When
%       invoked with left hand arguments,
%               [Y,X] = LSIM(A,B,C,D,U,T)
%               [Y,X] = LSIM(NUM,DEN,U,T)
%       returns the output and state time history in the matrices Y and X.
%       No plot is drawn on the screen.  Y has as many columns as there
%       are outputs, y, and with LENGTH(T) rows.  X has as many columns
%       as there are states.
%
%       See also: STEP,IMPULSE,INITIAL and DLSIM.

%       J.N. Little 4-21-85
%       Revised A.C.W.Grace 8-27-89
%       Copyright (c) 1985-89 by the MathWorks, Inc.

error(nargchk(4,7,nargin));

if (nargin==4),                 % transfer function description
        [num,den] = tfchk(a,b);
        u = c;
        t = d;
        % Convert to state space
        [a,b,c,d] = tf2ss(num,den);

elseif (nargin==5),
         error('Wrong number of input arguments.');
else
        error(abcdchk(a,b,c,d));
end

[ns,n] = size(a);
if (nargin==6)|(nargin==4),
        x0 = zeros(ns,1);
end

[p,m]=size(d);
if p*m==0, x=[]; if nargout~=0, yout=[]; end; return; end

if m==1, u=u(:); end, [nu,mu]=size(u);
t=t(:); nt = length(t);
```

```
% Make sure u has the right number of columns and rows.
if mu~=m, error('U must have the same number of columns as inputs.'); end
if nu~=nt, error('U must have the same number of rows as the length of T.'); end

TS=t(2)-t(1);
% First Order Hold Approximation

% For first order hold approximation first add m integrators in series
[a,b,c,d]=series(zeros(m),eye(m),eye(m),zeros(m),a,b,c,d);

% Get equivalent zero order hold discrete system
[A,B] = c2d(a,b,t(2)-t(1));

% For first order hold add (z-1)/TS in series
% This is equivalent to differentiating u.
% Transfer first sample to initial conditions.
x0=[zeros(m,1);x0(:)]+(b*u(1,:).');
u(1:nu-1,:)=(u(2:nu,:)-u(1:nu-1,:))/TS;
u(nu,:)=u(nu-1,:);

x = ltitr(A,B,u,x0);
y = x * c.' + u * d.';

% Remove the integrator state
x=x(:,1+m:n+m);

if nargout==0           % If no output arguments, plot graph
        plot(t,y), xlabel('Time (secs)'), ylabel('Amplitude')
        return % Suppress output
end
yout = y;
```

lsim_zoh.m

```
function  [y,x] = lsim_zoh(a, b, c, d, u, t, x0)
% This is the original Version 3.0 LSIM using a zoh on the input.
% (It is called DLSIM in Version 4.0)
%
%LSIM   Simulation of continuous-time linear systems to arbitrary inputs.
%       Y = LSIM(A,B,C,D,U,T)  calculates the time response of the system:
%                       .
%                       x = Ax + Bu
%                       y = Cx + Du
%
%       to input time history U.  Matrix U must have as many columns as
%       there are inputs, U.  Each row of U corresponds to a new time point,
%       and U must have LENGTH(T) rows. LSIM returns a matrix Y with as many
%       columns as there are outputs y, and with LENGTH(T) rows.
%       [Y,X] = LSIM(A,B,C,D,U,T) also returns the state time history.
%       LSIM(A,B,C,D,U,T,X0) can be used if initial conditions exist.
%
%       Y = LSIM(NUM,DEN,U,T) calculates the time response from the transfer
```

```
%       function description  G(s) = NUM(s)/DEN(s)  where NUM and DEN
%       contain the polynomial coefficients in descending powers.

%       J.N. Little 4-21-85
%       Copyright (c) 1985, 1986 by the MathWorks, Inc.

nargs = nargin;
if ((nargs == 4) | (nargs == 5))        % transfer function description
        if nargs == 5
                x0 = u;
        end
        u = c;
        t = d;
        [m,n] = size(a);
        % Convert to state space
        [a,b,c,d] = tf2ss(a,b);
        nargs = nargs + 2;
        end
end
[ns,nx] = size(a);
if (nargs == 6)
        x0 = zeros(1,ns);
end
error(nargchk(6,7,nargs));
error(abcdchk(a,b,c,d));

if min(size(u)) == 1
        u = u(:);
end
[a,b] = c2d(a,b,t(2)-t(1));
x = ltitr(a,b,u,x0);
y = x * c.' + u * d.';
```

mimo1.m

```
% mimo1.m
% Run ERA testcase MIMO1 using eraw.m
% (ERA written by Walter Ponge-Ferreira)
%

clear
load t1mimo1  % load data written by P76A_MIMO1.COM
whos

% convert to eraw format: yy(nst,ntim*nic), row i contains all data for output i
%  all ntim samples for input 1 stored first in the row, followed by all ntim
%  samples for input 2, etc.
%
yy=t1mimo1(:,1:30)';
yy=[yy t1mimo1(:,31:60)'];
yy=[yy t1mimo1(:,61:90)'];
whos
```

```
q=30     % No. of outputs
p=3      % No. of inputs
sf=100
r=10     % No. of block rows
s=10     % No. of block cols
time=[1,1,1,10,10]     % N1,N2,N3,N2LAST,N3LAST
trunc=[0,0,101,30,8]   % RNKTOL,MXFLAG,POFVAR,MXORDR,IORDTU

[l,psi,mpf,emac,mpc,cmi,sv,fd,zetap,clktime]=...
eraw(yy,q,p,sf,r,s,time,trunc);
clktime

fprintf('              fd, Hz       zetap        cmi');
fprintf('        emac     mpc-w\n')
iorder=length(fd);
for i=1:iorder
  fprintf(' %4.0f:   %10.3f    %8.3f\',i,fd(i),zetap(i));
  fprintf('    %8.2f   %8.2f   %8.2f\n',cmi(i),emac(i),mpc(i));
end

clg
subplot(221),plot(real(psi(:,1))),title('Mode 1')
subplot(222),plot(real(psi(:,2))),title('Mode 2')
subplot(223),plot(real(psi(:,3))),title('Mode 3')
```

modal_par_theory.m

```
% modal_par_theory.m
%
% Compute modal parameters of 2 dof example in Theory chapter
% of ERA User's Guide (Table 2-1).
%
% R. Pappa  6-23-93
%

j = sqrt(-1);

m1 = 0.8; m2 = 1.5; g = 0.1; k = 10;

M = [m1 0 ; 0 m2]
K = [2*k -k ; -k 2*k]
G = [2*g -g ; -g 2*g]  % (Proportional damping => real modes)

ac = [zeros(2) eye(2) ; -M\K -M\G];
bc = [zeros(2) ; inv(M)];
c  = [eye(2) zeros(2)];
d  = zeros(2);

[wn,zeta] = damp(ac);
fn0 = wn/(2*pi);
fd = fn0 .* sqrt(1-zeta.*zeta)
zetap = zeta * 100
```

```
[phi_unsorted,wn2] = eig(K,M);
fn_unsorted = sqrt(diag(wn2))/(2*pi);
[fn,sort_indices] = sort(fn_unsorted)
phi0 = phi_unsorted(:,sort_indices);
maxes = max(phi0);
phi_ampl_scaled = phi0 * 100 * diag(1 ./ maxes)
phitmphi = phi0' * M * phi0;
phi_mass_scaled = phi0 * diag([1/sqrt(phitmphi(1,1)),1/sqrt(phitmphi(2,2))])
```

okid_prfs_af_theory.m

```
% okid_prfs_af_theory.m
%
% Compute pulse response of discrete system using general
% input-output data and OKID, and compare with PRF calculated
% with DLSIM.
%
% Save all results as ASCII files
%
% ACCELERATION RESPONSE
%
% R. Pappa  2-8-94
%

j = sqrt(-1);

m1 = 0.8; m2 = 1.5; g = 0.1; k = 10;

M = [m1 0 ; 0 m2]
G = [2*g -g ; -g 2*g]
K = [2*k -k ; -k 2*k]

ac = [zeros(2) eye(2) ; -M\K -M\G]
bc = [zeros(2) ; inv(M)]
c  = [-M\K -M\G]
d  = inv(M)

sf = 2.0
dt = 1/sf;
ntpts = 250 % No. of time points in time sim. PRF
%             and in OKID PRF to calculate

t = [0:dt:(ntpts-1)*dt]';

[ad,bd] = c2d(ac,bc,dt);

u_pulse = zeros(size(t));
u_pulse(1) = 1.0;

ninputs=2; noutputs = 2;
p_okid = 5
ntpts_random = 200 % No. of random input-output data pts. to use in OKID
```

```
randn('seed',0);

u_random = randn(ntpts_random,2);
nstates = length(ad);
x0 = randn(nstates,1); % Include random i.c. to make it challenging
% x0 = zeros(nstates,1);
y_random = dlsim(ad,bd,c,d,u_random,x0);

% Plot the 2 inputs and outputs if plot_ins_and_outs = 1

plot_ins_and_outs = 0
if plot_ins_and_outs == 1

t_random = [0:dt:(ntpts_random-1)*dt]';

for innumtu = 1:2
clf
[xxx,yyy] = stairs(t_random,u_random(:,innumtu));
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('Random Excitation')
title(['Excitation No. ',num2str(innumtu)])
pause
end % End of innumtu loop

for outnumtu = 1:2
clf
[xxx,yyy] = stairs(t_random,y_random(:,outnumtu));
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('D/F Random Response')
title(['Response No. ',num2str(outnumtu),' Without Initial Conditions'])
pause
end % End of outnumtu loop

end % End of plot_ins_and_outs loop

[ys,yo] = pulse(noutputs,ninputs,dt,u_random,y_random,...
p_okid,ntpts,'nodesc');

for innum = 1:2
for outnum = 1:2
innum,outnum

y_pulse = dlsim(ad,bd(:,innum),c(outnum,:),d(outnum,innum),u_pulse);

% Plot OKID Results

clf
islot = (innum - 1)*noutputs + outnum;
ys_innum_outnum = ys(:,islot);
[xxx,yyy] = stairs(t,ys_innum_outnum);
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('A/F Pulse Response')
title('A/F PRF from OKID')
```

```
% Store this prf in prf_okid_innum_all
if innum == 1
 prf_okid_1_all(:,outnum) = ys_innum_outnum;
elseif innum == 2
 prf_okid_2_all(:,outnum) = ys_innum_outnum;
else
 error('innum must be 1 or 2')
end

pause

clf
[xxx,yyy] = stairs(t,y_pulse);
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('A/F Pulse Response')
title('A/F PRF from time simulation')

% Store this prf in prf_lsim_innum_all
if innum == 1
 prf_lsim_1_all(:,outnum) = y_pulse;
elseif innum == 2
 prf_lsim_2_all(:,outnum) = y_pulse;
else
 error('innum must be 1 or 2')
end

pause

% Plot difference: time simulation - OKID result

y_diff = y_pulse - ys_innum_outnum;
clf
[xxx,yyy] = stairs(t,y_diff);
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('A/F Pulse Response')
title('Difference: Time Simulation - OKID Result')
pause

% Now, make overlay plot of beginning of each function

len_short = min([50 ntpts]);
t_short = t(1:len_short);

clf
[xxx,yyy] = stairs(t_short,y_pulse(1:len_short));
plot(xxx,yyy,'k-')
hold on
[xxx,yyy] = stairs(t_short,ys_innum_outnum(1:len_short));
plot(xxx,yyy,'k--')
plot(t_short,y_pulse(1:len_short),'+')
plot(t_short,ys_innum_outnum(1:len_short),'o')
hold off
xlabel('Time, sec'),ylabel('A/F Pulse Response')
title(['Time Simulation = Solid line (+), OKID = Dashed line (o).' ...
```

```
' ntpts_random = ',num2str(ntpts_random)])
pause

end % End of outnum=1:2 loop
end % End of innum=1:2 loop

% Save all results on disk in ASCII format

save prfs_af_okid_1.asc prf_okid_1_all /ascii
save prfs_af_okid_2.asc prf_okid_2_all /ascii
save prfs_af_lsim_1.asc prf_lsim_1_all /ascii
save prfs_af_lsim_2.asc prf_lsim_2_all /ascii
```

okid_prfs_df_theory.m

```
% okid_prfs_df_theory.m
%
% Compute pulse response of discrete system using general
% input-output data and OKID, and compare with PRF calculated
% with DLSIM.
%
% Save all results as ASCII files
%
% DISPLACEMENT RESPONSE
%
% R. Pappa  2-8-94
%

j = sqrt(-1);

m1 = 0.8; m2 = 1.5; g = 0.1; k = 10;

M = [m1 0 ; 0 m2]
G = [2*g -g ; -g 2*g]
K = [2*k -k ; -k 2*k]

ac = [zeros(2) eye(2) ; -M\K -M\G]
bc = [zeros(2) ; inv(M)]
c  = [eye(2) zeros(2)]
d  = zeros(2)

sf = 2.0
dt = 1/sf;
ntpts = 250 % No. of time points in time sim. PRF
%             and in OKID PRF to calculate

t = [0:dt:(ntpts-1)*dt]';

[ad,bd] = c2d(ac,bc,dt);

u_pulse = zeros(size(t));
u_pulse(1) = 1.0;
```

```
ninputs=2; noutputs = 2;
p_okid = 5
ntpts_random = 200 % No. of random input-output data pts. to use in OKID

randn('seed',0); % Reset seed

u_random = randn(ntpts_random,2);
nstates = length(ad);
% x0 = randn(nstates,1); % Include random i.c. to make it challenging
x0 = zeros(nstates,1); % or set i.c.'s to zero
y_random = dlsim(ad,bd,c,d,u_random,x0);

% Plot the 2 inputs and outputs if plot_ins_and_outs = 1

plot_ins_and_outs = 0
if plot_ins_and_outs == 1

t_random = [0:dt:(ntpts_random-1)*dt]';

for innumtu = 1:2
clf
[xxx,yyy] = stairs(t_random,u_random(:,innumtu));
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('Random Excitation')
title(['Excitation No. ',num2str(innumtu)])
pause
end % End of innumtu loop

for outnumtu = 1:2
clf
[xxx,yyy] = stairs(t_random,y_random(:,outnumtu));
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('D/F Random Response')
title(['Response No. ',num2str(outnumtu),' Without Initial Conditions'])
pause
end % End of outnumtu loop

end % End of plot_ins_and_outs loop

[ys,yo] = pulse(noutputs,ninputs,dt,u_random,y_random,...
p_okid,ntpts,'nodesc');

for innum = 1:2
for outnum = 1:2
innum,outnum

y_pulse = dlsim(ad,bd(:,innum),c(outnum,:),d(outnum,innum),u_pulse);

% Plot OKID Results

clf
islot = (innum - 1)*noutputs + outnum;
ys_innum_outnum = ys(:,islot);
[xxx,yyy] = stairs(t,ys_innum_outnum);
```

```
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('D/F Pulse Response')
title('D/F PRF from OKID')

% Store this prf in prf_okid_innum_all
if innum == 1
 prf_okid_1_all(:,outnum) = ys_innum_outnum;
elseif innum == 2
 prf_okid_2_all(:,outnum) = ys_innum_outnum;
else
 error('innum must be 1 or 2')
end

pause

clf
[xxx,yyy] = stairs(t,y_pulse);
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('D/F Pulse Response')
title('D/F PRF from time simulation')

% Store this prf in prf_lsim_innum_all
if innum == 1
 prf_lsim_1_all(:,outnum) = y_pulse;
elseif innum == 2
 prf_lsim_2_all(:,outnum) = y_pulse;
else
 error('innum must be 1 or 2')
end

pause

% Plot difference: time simulation - OKID result

y_diff = y_pulse - ys_innum_outnum;
clf
[xxx,yyy] = stairs(t,y_diff);
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('D/F Pulse Response')
title('Difference: Time Simulation - OKID Result')
pause

% Now, make overlay plot of beginning of each function

len_short = min([50 ntpts]);
t_short = t(1:len_short);

clf
[xxx,yyy] = stairs(t_short,y_pulse(1:len_short));
plot(xxx,yyy,'k-')
hold on
[xxx,yyy] = stairs(t_short,ys_innum_outnum(1:len_short));
plot(xxx,yyy,'k--')
plot(t_short,y_pulse(1:len_short),'+')
```

```
plot(t_short,ys_innum_outnum(1:len_short),'o')
hold off
xlabel('Time, sec'),ylabel('D/F Pulse Response')
title(['Time Simulation = Solid line (+), OKID = Dashed line (o).' ...
' ntpts_random = ',num2str(ntpts_random)])
pause

end % End of outnum=1:2 loop
end % End of innum=1:2 loop

% Save all results on disk in ASCII format

save prfs_df_okid_1.asc prf_okid_1_all /ascii
save prfs_df_okid_2.asc prf_okid_2_all /ascii
save prfs_df_lsim_1.asc prf_lsim_1_all /ascii
save prfs_df_lsim_2.asc prf_lsim_2_all /ascii
```

prfs_af_theory.m

```
% prfs_af_theory.m
%
% Compute pulse response of discrete system, and compare with
% IRF computed by IFFT.
%
% Save all results as ASCII files
%
% ACCELERATION RESPONSE
%
% R. Pappa  6-29-93
%

j = sqrt(-1);

m1 = 0.8; m2 = 1.5; g = 0.1; k = 10;

M = [m1 0 ; 0 m2]
G = [2*g -g ; -g 2*g]
K = [2*k -k ; -k 2*k]

ac = [zeros(2) eye(2) ; -M\K -M\G]
bc = [zeros(2) ; inv(M)]
c  = [-M\K -M\G]
d  = inv(M)

sf = 2.0;
Nyquist_freq = sf/2
nflines = 125
dt = 1/sf;
df = (sf/2)/nflines;
f = [0 : df : sf/2];
w = 2 * pi * f;

ntpts = 2 * nflines
```

```
t = [0:dt:(ntpts-1)*dt]';

u = zeros(size(t));
u(1) = 1.0;

% innum=1; outnum = 1;
for innum = 1:2
for outnum = 1:2
innum,outnum

[ad,bd] = c2d(ac,bc,dt);
y = dlsim(ad,bd(:,innum),c(outnum,:),d(outnum,innum),u);

% Compare with PRF computed as IFFT of FRF

[magc,phasec] = dbode(ad,bd,c(outnum,:),d(outnum,:),dt,innum,w);
phasec_rad = phasec/180. * pi;
gz = magc .* (cos(phasec_rad) + j*sin(phasec_rad));

% calculate prf using 0 - sf/2 data

gz(1) = real(gz(1));gz(ntpts/2+1)=real(gz(ntpts/2+1));
gz(ntpts/2+2:ntpts) = conj(flipud(gz(2:ntpts/2)));

y_ifft_gz = real(ifft(gz));
y_ifft_gz = y_ifft_gz(1:length(t));

% Plot Results

clf
[xxx,yyy] = stairs(t,y);
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('A/F Pulse Response')
title('A/F PRF from time simulation')

% Store this prf in prf_lsim_innum_all
if innum == 1
 prf_lsim_1_all(:,outnum) = y;
elseif innum == 2
 prf_lsim_2_all(:,outnum) = y;
else
 error('innum must be 1 or 2')
end

pause

clf
[xxx,yyy] = stairs(t,y_ifft_gz);
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('A/F Pulse Response')
title('A/F PRF from IFFT of FRF')

% Store this prf in prf_ifft_innum_all
if innum == 1
```

```
 prf_ifft_1_all(:,outnum) = y_ifft_gz;
elseif innum == 2
 prf_ifft_2_all(:,outnum) = y_ifft_gz;
else
 error('innum must be 1 or 2')
end

pause

% Plot difference: time simulation - IFFT result

y_diff = y - y_ifft_gz;
clf
[xxx,yyy] = stairs(t,y_diff);
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('A/F Pulse Response')
title('Difference: Time Simulation - IFFT')

pause

% Now, make overlay plot of beginning of both functions

len_short = 50;
t_short = t(1:len_short);

clf
[xxx,yyy] = stairs(t_short,y(1:len_short));
plot(xxx,yyy,'k-')
hold on
[xxx,yyy] = stairs(t_short,y_ifft_gz(1:len_short));
plot(xxx,yyy,'k--')
plot(t_short,y(1:len_short),'+')
plot(t_short,y_ifft_gz(1:len_short),'o')
hold off
xlabel('Time, sec'),ylabel('A/F Pulse Response')
title('Time Simulation = Solid line (+), IFFT of FRF = Dashed line (o)')

pause

end % End of outnum=1:2 loop
end % End of innum=1:2 loop

% Save all results on disk in ASCII format

save prfs_af_lsim_1.asc prf_lsim_1_all /ascii
save prfs_af_lsim_2.asc prf_lsim_2_all /ascii
save prfs_af_ifft_1.asc prf_ifft_1_all /ascii
save prfs_af_ifft_2.asc prf_ifft_2_all /ascii
```

prfs_df_theory.m

```
% prfs_df_theory.m
%
```

```
% Compute pulse response of discrete system, and compare with
% IRF computed by IFFT.
%
% Save all results as ASCII files
%
% DISPLACEMENT RESPONSE
%
% R. Pappa  6-29-93
%

j = sqrt(-1);

m1 = 0.8; m2 = 1.5; g = 0.1; k = 10;

M = [m1 0 ; 0 m2]
G = [2*g -g ; -g 2*g]
K = [2*k -k ; -k 2*k]

ac = [zeros(2) eye(2) ; -M\K -M\G]
bc = [zeros(2) ; inv(M)]
c  = [eye(2) zeros(2)]
d  = zeros(2)

sf = 2.0;
Nyquist_freq = sf/2
nflines = 125
dt = 1/sf;
df = (sf/2)/nflines;
f = [0 : df : sf/2];
w = 2 * pi * f;

ntpts = 2 * nflines
t = [0:dt:(ntpts-1)*dt]';

u = zeros(size(t));
u(1) = 1.0;

% innum=1; outnum = 1;
for innum = 1:2
for outnum = 1:2
innum,outnum

[ad,bd] = c2d(ac,bc,dt);
y = dlsim(ad,bd(:,innum),c(outnum,:),d(outnum,innum),u);

% Compare with PRF computed as IFFT of FRF

[magc,phasec] = dbode(ad,bd,c(outnum,:),d(outnum,:),dt,innum,w);
phasec_rad = phasec/180. * pi;
gz = magc .* (cos(phasec_rad) + j*sin(phasec_rad));

% calculate prf using 0 - sf/2 data

gz(1) = real(gz(1));gz(ntpts/2+1)=real(gz(ntpts/2+1));
```

```
gz(ntpts/2+2:ntpts) = conj(flipud(gz(2:ntpts/2)));

y_ifft_gz = real(ifft(gz));
y_ifft_gz = y_ifft_gz(1:length(t));

% Plot Results

clf
[xxx,yyy] = stairs(t,y);
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('D/F Pulse Response')
title('D/F PRF from time simulation')

% Store this prf in prf_lsim_innum_all
if innum == 1
 prf_lsim_1_all(:,outnum) = y;
elseif innum == 2
 prf_lsim_2_all(:,outnum) = y;
else
 error('innum must be 1 or 2')
end

pause

clf
[xxx,yyy] = stairs(t,y_ifft_gz);
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('D/F Pulse Response')
title('D/F PRF from IFFT of FRF')

% Store this prf in prf_ifft_innum_all
if innum == 1
 prf_ifft_1_all(:,outnum) = y_ifft_gz;
elseif innum == 2
 prf_ifft_2_all(:,outnum) = y_ifft_gz;
else
 error('innum must be 1 or 2')
end

pause

% Plot difference: time simulation - IFFT result

y_diff = y - y_ifft_gz;
clf
[xxx,yyy] = stairs(t,y_diff);
plot(xxx,yyy,'k-')
xlabel('Time, sec'),ylabel('D/F Pulse Response')
title('Difference: Time Simulation - IFFT')

pause

% Now, make overlay plot of beginning of both functions
```

```
len_short = 50
t_short = t(1:len_short);

clf
[xxx,yyy] = stairs(t_short,y(1:len_short));
plot(xxx,yyy,'k-')
hold on
[xxx,yyy] = stairs(t_short,y_ifft_gz(1:len_short));
plot(xxx,yyy,'k--')
plot(t_short,y(1:len_short),'+')
plot(t_short,y_ifft_gz(1:len_short),'o')
hold off
xlabel('Time, sec'),ylabel('D/F Pulse Response')
title('Time Simulation = Solid line (+), IFFT of FRF = Dashed line (o)')

pause

end % End of outnum=1:2 loop
end % End of innum=1:2 loop

% Save all results on disk in ASCII format

save prfs_df_lsim_1.asc prf_lsim_1_all /ascii
save prfs_df_lsim_2.asc prf_lsim_2_all /ascii
save prfs_df_ifft_1.asc prf_ifft_1_all /ascii
save prfs_df_ifft_2.asc prf_ifft_2_all /ascii
```

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The Eigensystem Realization Algorithm (ERA) is a multiple-input, multiple-output, time domain technique for structural modal identification and minimum-order system realization. Modal identification is the process of calculating structural eigenvalues and eigenvectors (natural vibration frequencies, damping, mode shapes, and modal masses) from experimental data. System realization is the process of constructing state-space dynamic models [A,B,C,D] for modern control design. This User's Guide documents VAX/VMS-based FORTRAN software developed by the author since 1984 in conjunction with many applications. It consists of a main ERA program and 66 pre- and post-processors. The software provides complete modal identification capabilities and most system realization capabilities.

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